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(E77-10170) APPLICATION OF STANDARD PHOTOGEOLOGIC TECHNIQUES TO LANDSAT IMAGERY FOR MINERAL EXPLORATION IN THE BASIN AND RANGE PROVINCE OF UTAH AND NEVADA Final Report (Utah Univ.) 243 p HC A11/MF A01

N77-26572

Unclas
G3/43 00170

APPLICATION OF STANDARD PHOTOGEOLOGIC TECHNIQUES TO LANDSAT IMAGERY FOR MINERAL EXPLORATION IN THE BASIN AND RANGE PROVINCE OF UTAH AND NEVADA

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June, 1977

FINAL REPORT

Prepared for

GODDARD SPACE FLIGHT CENTER

Greenbelt, Maryland 20771

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Application of standard photogeologic techniques to Landsat Imagery for Mineral Exploration in the Basin & Range Province of Utah and Nevada		5. Report Date June, 1977 6. Performing Organization Code
7. Author(s) Laurence H. Lattman, C. E. Cronenwett, M. R. Smith, T. A. Belchak		8. Performing Organization Report No.
9. Performing Organization Name and Address University of Utah Salt Lake City, Utah 84102		10. Work Unit No. 11. Contract or Grant No. NAS5-20955
12. Sponsoring Agency Name and Address National Aeronautics Space Administration Goddard Space Flight Center Greenbelt, Maryland 20771		13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code
15. Supplementary Notes --------		

16. Abstract Standard photogeologic techniques were applied to Landsat imagery of the Basin and Range province of Utah and Nevada to relate linear, tonal, textural, drainage and geomorphic features to known mineralized areas in an attempt to develop criteria for the location of mineral deposits. No consistent correlation was found between lineaments, mapped according to specified criteria, and locations of mines, mining districts, or intrusive outcrops. Drainage patterns mapped from Landsat show more control by slope than by rock type. Tonal and textural patterns are more closely related to geologic outcrop patterns than to mineralization. A statistical study of drainage azimuths of various length classes as measured on Landsat showed significant correlation with mineralized districts in the length class of 3-6 km.

Alignments of outcrops of basalt, a rock type highly visible on Landsat imagery, appear to be colinear with acidic and intermediate intrusive centers in some areas and may assist on the recognition of regional fracture systems for mineral exploration.

17. Key Words (Selected by Author(s))	18. Distribution Statement
Landsat, photogeologic techniques, mineral exploration, Basin & Range, lineaments, basalts	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*

ABSTRACT

Utah - Nevada Study Area

The purpose of this report was to establish possible methods for, and evaluation of, the use of Landsat imagery as a practical tool for mineral exploration, using standard photogeologic techniques.

The area examined in this study is in the complexly folded and faulted Basin and Range province of Utah and Nevada. Within this area 241 mining districts were tabulated for this report.

The results of this report are restricted to the Basin and Range province and those portions of the Colorado Plateau as noted. The writers do not presume that their conclusions are necessarily applicable to other geologic or tectonic provinces.

Lineament studies were made using specified criteria for the selection of lineaments from the Landsat imagery, and the lineaments thus mapped were related to intrusions and mining districts within the study area. No clear criteria for the identification of either intrusions or mineralized areas using the Landsat imagery were found. No valid relationships were noted between the lineaments and intrusions, alignments of intrusions, or mining districts. The lineaments located in these studies tend to bound rather than cross mining districts.

Geomorphic studies were made to relate features mappable on Landsat imagery with intrusions or areas of mineralization. These included drainage patterns, slope studies and tonal and textural boundaries. No consistent relationships were found.

The attempt to identify lineaments from Landsat imagery was also made on the basis of measurements of stream length and azimuth. A statistical comparison of data in mineralized and non-mineralized areas indicated a significant difference in the number of streams in the length range of 3.2-6.4 km and a northeast azimuth in mineralized areas.

An attempt was made to relate drainage patterns shown at the Army Map Service (AMS) quadrangle scale (1:250,000) to valley-stream/lineament alignments taken from Landsat. Drainages at the AMS scale appear to be too coarse to accurately display a definitive relation to structure or strati-

graphic controls although they are a useful compliment to lineament identification studies in northwest and southeast quadrants.

An attempt was made to relate lineaments of mineralized and non-mineralized areas noted on Landsat to categories of contour forms as recognized on topographic maps. Contours defining valleys and their associated ridges are most consistently selected for lineament trends with valleys chosen for non-mineralized areas. Variations in recognition criteria were believed to account for operator preference.

Drainage pattern, slope shape, and tonal and textural boundary studies were made in an attempt to identify intrusions on Landsat. No consistently reliable criteria were found.

The utilization of basalt cone and flow alignments as a guide to regional mineral trend identification was investigated. Basalts are the most consistently identifiable petrographic type noted on the Landsat imagery within the study area. In some areas alignments of basalts appear to be colinear with alignments of mining districts and intrusive igneous bodies. The results of this study suggest that basalt cone and flow alignments, if they are a surface manifestation of deep seated fracture zones, may define regional fracturing - and associated mineralization - which itself is not apparent on Landsat imagery.

EXECUTIVE SUMMARY

The goal of this project was to establish possible methods and criteria for using LANDSAT multispectral scanner imagery in conjunction with airborne remote sensing data as a practical and productive tool for mineral exploration.

The study area, selected on the basis of recognized mineralization, is a 220 km wide strip extending across the Basin and Range province in western Utah and Nevada. All large active or abandoned mining districts operated in the 19th and 20th centuries were catalogued and those reported to have been initially discovered because of one or more surface manifestations were identified. The present state of each of the larger mining districts was examined on available imagery and aerial photographs to determine whether the surface features reported for these districts are large enough to be observed by remote sensing. None of the discovery features that were large enough to be distinguished on LANDSAT or other imagery could be distinguished from non-mineralized features without prior knowledge of the area. For this reason, no computer enhancement techniques were employed.

Since the authors were unable to identify mineralized areas with the use of Landsat imagery in the Utah-Nevada study area, photogeologic techniques were used to locate geologic, structural, or geomorphic features on the imagery which might identify intrusions or their related mineralization. These features, visible as lines, tones, or textural boundaries, were mapped in areas where the geology was not known to the operators, then compared with geologic maps to test their applicability for mineral exploration.

Lineament studies were initiated by setting up specific criteria for the selection of lineaments on Landsat imagery, to facilitate reproducibility. Over 200 lineaments were mapped from a 1:250,000 scale Landsat mosaic of the Utah-Nevada study area. Selection criteria included a minimum length of 5 km; at least 50% topographic expression; continuity across a ridge or drainage divide to insure that they are more than simple consequent drainages, and recognition by at least two operators. The lineaments were plotted on $1^{o} \times 2^{o}$ AMS topographic sheets, then traced onto transparent overlays. The lengths and azimuths of the lineaments were measured.

To determine if mines and mining districts are preferentially located on the lineaments so chosen, or on their intersections, the lineaments were compared with the location of 666 mines plotted within the study area. Eighty mines were found to lie within 1 km of a lineament and 7 to lie within 1 km of an intersection. Two thirds of the lineaments had no mine within 5 km.

To further test the lineament-mine relationship, an average width of 2 km was assumed for the lineaments in the above study, and their areas determined for each AMS sheet area (or portion thereof) within the study area. The number of mines located on each of the 14 sheets was tallied, and the percent of mines lying on the lineaments was determined and divided by the percent of the area covered by the lineaments. The resulting ratios were reasonably consistent for all of the AMS sheet areas except for three, located in western Utah. Two of these three areas (Tooele and Delta) contain unusually large areas of Quaternary sediments. The actual area of outcrop was measured for mine AMS sheet areas, including the three with the high ratios, and the ratios were recalculated on the basis of actual outcrop area. The results indicated that the large areas of Quaternary sediments and Tertiary outcrop on the three sheets account for the anomalous ratios.

No significant correlation was found between the lineaments selected for this study and the location of the mines.

A test was made to determine if a larger proportion of the mines fall along lineaments of a preferred azimuth. The lineaments selected in the first study were divided into 20° classes and the mines on the lineaments of each class tallied. No strong preference was found.

To find if several mines lying along the same lineament show evidence of having a common source of mineralization, the metal production was compared for 12 mines lying along four lineaments mapped in the first study on the Reno AMS sheet. There was no evidence of uniform metal production from mines lying along the same lineament.

To find if more mines lie on lineaments than on mapped faults, the total length of lineaments mapped in the first study on four AMS sheets (Tooele, Delta, Price, and Salt Lake) and the total length of faults mapped on the same area of the Geologic Map of Utah, at the same scale, were measured. The total number of mines on lineaments, and mines on mapped faults was tallied. No consistent relationships were found; for the four sheet area there was an average of 68 km of faults per mine and 58 km of lineaments.

Since the initial selection of lineaments showed little correlation with the location of the mines, several studies were made using lineaments mapped within a limited azimuthal range. Lineaments within 10° of north were mapped on the Walker Lake AMS sheet area from 1:250,000 scale Landsat prints. These had a minimum length of 2 km and followed all natural linear features visible on the imagery. These lineaments did not coincide with known north-south alignments of mines and mining districts, but instead appeared to separate areas of mineralization (mining districts) from barren areas within the ranges.

A second set of lineaments having an azimuth within 10° of east was mapped in the same area. Again the lineaments tended to separate rather than cross through the mining districts. The districts thus separated may produce different suites of metals.

Further tests were made to find if lineaments of any azimuth actually cross mining districts. Four areas which contain 10 mining districts were selected in central Nevada and north-central Utah. Lineaments were mapped for these areas on both Landsat 1:250,000 scale prints and U-2 color transparencies. All natural linear features visible as sharp lines or boundaries greater than 2 km in length were mapped. No lineament was found to cross any of the mining districts as a continuous line, although some lineaments could be traced as alignments of broken and offset linear features across the districts. These were found to be unrelated to the reported mineralized structures. Relatively unbroken and continuous lineaments were found as boundaries of mining districts, as in the previous study, or as range front boundaries.

Comparison of 40 intersections of lineaments, located on the Reno AMS sheet area in the initial lineament study, with geologic maps of the same scale showed no relationship to the mapped structures. Only six lineament intersections fell on mapped faults.

A study was made to evaluate the effect of scale by mapping a prominant lineament in central Nevada on 1:1,000,000, 1:500,000 and 1:250,000 scale Landsat imagery. The larger scales show greater scattering and segmentation of the linear features which define the lineaments.

A lineament across the central Wasatch Mountains was mapped from Landsat 1:250,000 scale prints, compared with geologic maps at the same scale (1:250,000) and field checked at several places along its length. It

was found to follow geologic contacts and mapped faults for about 40% of its length. In the field, it could be traced only if its location and continuity had been previously determined from the Landsat imagery.

Studies were made to see if lineament patterns could be found which might be used to identify intrusions on Landsat imagery. For the first study, initial observations had suggested that the absence of lineament intersections on a lineament map might indicate the presence of intrusions, perhaps because the process of intrusion had obliterated older lineaments. A follow up study did not confirm the initial observation, however.

For a second intrusion identification study, it was suggested that northeasterly trending lineaments might be masked within intrusions. Northeasterly and northwesterly lineaments, from both Landsat imagery and U-2 color transparencies, were mapped across several intrusions in western Nevada. Three categories of lineaments were counted: those bounding the intrusions, those crossing the intrusion, and those terminated within the intrusions. Chi^2 tests were made to determine preferred orientation; none was found.

To test if alignments of intrusions follow a single lineament, three alignments of intrusions from 225 to 250 km in length were selected from the Intrusive Map of Nevada. Two of the alignments are parallel to range axes (N-S and N 30^o E); the third crosses the ranges in north-central Nevada in an easterly direction. Lineaments parallel to the alignments were mapped from a 1:1,000,000 scale Landsat mosaic of the study area. These lineaments had a minimum length of 10 km, and followed drainages, faults, range front boundaries, and other linear geomorphic features. Lineaments were found parallel to and alongside the N-S and N 30^o E alignments. Within the alignments of intrusions the lineaments are broken and somewhat scattered. No lineaments were found to parallel the E-W alignment. This suggested that the lineaments which follow the Basin and Range outcrop pattern may create apparent alignments by differential uplift but they are not necessarily related to the emplacement of the intrusions.

To study the distribution of intrusions in Nevada, a 20 km^2 grid was overlaid on the Intrusive map of Nevada and the intrusions within each square counted. Concentration of intrusions is shown in the western part of the state in both the N-S and N 30^o E orientation, parallel to two of the

alignments studied above, and parallel to the major trends of the ranges. To test if these alignments are simply the result of outcrop distribution, the actual area of outcrop was measured by 20 km^2 quads in eastern Nevada. This count was compared with the number of intrusive outcrops in each quad. The number of intrusive outcrops is not a simple function of the area of outcrop.

The general lack of colinearity found in these studies between lineaments and intrusions or mining districts suggests either that any relationship may be random, or that those lineaments which may have controlled the emplacement of intrusions and mineralization are not now visible as continuous linear structures in the tectonically active Basin and Range province.

To find if drainage patterns can be used to identify intrusive outcrops, drainage patterns were mapped across three areas of intrusive outcrop. from Landsat and U-2 imagery. These patterns were compared with the outcrop pattern on geologic maps. It was found that topography has more effect on the type of drainage pattern than does the lithology.

A second drainage study area tested the Battle Mountain-Eureka mineral trend of central Nevada. Here the geologic maps indicate normal and thrust faulting, and clastic, siliceous, and carbonate strata. Drainages were categorized by length and azimuth. When statistically compared the data showed that the concentration of the 3.2 - 6.4 (2-4 mi) segments in the N 30-60^{o} E direction appeared to be associated with the mineralized areas. This approach warrants further work in less complex areas to test for general applicability.

When the length of valley/stream lineament segments in the Battle Mountain special study area was related to azimuth it was found that in non-mineralized areas those in excess of 16 km (10 mi) showed a marked preference for the N 0-30^{o} E direction. Segments reaching this length, however, are generally related to range front faults that often exhibit linear continuity in the Basin and Range province and in this area are preferentially oriented northeast.

A comparison of valley-stream/lineaments selected from Landsat in the Battle Mountain special study area exhibit a weak correspondence with regional geology. The most consistent correlation occurs where faults parallel the axial trend of mountain ranges. There is little or no accordance with faults with trend perpendicular to range axes. Matching of valley-stream/

lineaments with lithologic contacts was infrequent; the best definition of the faults occurs in volcanic stata.

Valley-stream/lineaments selected from Landsat in the Battle Mountain area were compared with drainages traced from topographic maps at the same scale. The latter were selected on the basis of annotation by a stream symbol. They relate best to local geomorphic features, showing little obvious regard for bedrock control. At the scale of 1:250,000 the map drainage density was considerably less than for the same area imaged on Landsat. In addition, topographic map drainages show no azimuthal preference when mineralized and non-mineralized areas were compared. They may, however, provide a useful adjunct to Landsat scenes in northwest and southeast quadrants where shadow contrast is suppressed by the scanning direction relative to sun elevation and azimuth.

In the Battle Mountain special study area a test was made to determine what grouping of topographic contours correlate with linear features perceived by an operator as lineaments on Landsat imagery. Contour analogues of Landsat lineaments in mineralized and non-mineralized areas are separable into six categories. Of these it was found that the contours which represented valleys and ridge lines were the two categories most consistently identified as lineaments. Ridge lines were selected most frequently in mineralized areas and valleys selected most frequently in non-mineralized areas. Obviously, valleys and ridges form complimentary pairs. The apparent preference for one or the other in a given scene would seem to be as likely related to variations in scene, band or seasonal recognition criteria as to genetic geomorphic differences related to mineralization.

To test if weathering differences could be used to distinguish intrusions from surrounding country rock, slope shapes and shapes of interstream ridges were tallied along major drainages across four areas containing intrusive outcrops in western Nevada, from stereo-pairs of U-2 color transparencies. No consistent slope pattern was found which could permit intrusions to be distinguished from non-intrusive rock. Because of these negative results on U-2 imagery, no effort was made to test slope shapes on Landsat imagery.

In a study to determine if mineralized rock could be distinguished from non-mineralized rock by tonal and textural contrast on unenhanced Landsat imagery, these boundaries were outlined for two mining districts in central Nevada. The boundaries were found to correlate well with geologic boundaries when compared with the geologic maps of the districts, but they could not be used to distinguish mineralized rock from non-mineralized rock. Basalt

is one of the most consistently identifiable rock types on Landsat imagery. This was indicated by a study involving a comparative visual examination of the imagery with geologic maps at scales which ranged from 1:1,000,000 to 1:100,000. A further study of the plot of all basalt outcrops in the project area suggests that their arrangement is not haphazard. Locally they appear to form alignments, colinear with silica-rich intrusives, (granites, monzonites, etc.), which are traceable for distances of more than 150 kilometers. Of significance to the mineral explorationist, many of these acidic intrusions are attended by mineralization.

The premise that magmas of such divergent composition utilize the same regional fracture systems suggested that linear basalt outcrop patterns viewed from the vantage of Landsat might serve as guides to regional mineralization trends.

To test this premise, stratigraphic information from Landsat and geologic maps was integrated on base maps in an attempt to locate regional fracture systems by the method of basalt outcrop alignments. The azimuths of these alignments formed a regional grid system which was related to the locus of intrusive bodies. Intersections on the grid which do not have mapped intrusions are postulated as potential sites for intrusive loci. Subsequent work should be directed to verification of the validity, the determination of grid spacing and geographical accuracy of these grid intersections. Image enhancement techniques should be applied to improve and enlarge the recognition criteria for basalt.

In conclusion, if lineaments are mapped in the Basin and Range province using the strict mapping criteria of this report, they do not appear to be directly or simply related to mineralization. The most significant relationship appears to be that they separate areas generally mineralized from barren areas. Also, the lineaments appear to be locally discontinuous across mining districts.

No geomorphic parameters such as drainage geometry or slope form appears to consistently distinguish intrusive areas or mineralized from non-mineralized intrusives.

Colinear acidic and basaltic igneous masses may define mineral belts and be related to regional fractures which in themselves are not apparent on Landsat imagery.

SUMMARY OF CONCLUSIONS

LINEAMENT STUDIES

To find if intrusions or mining districts can be located using standard photogeologic techniques on Landsat imagery, lineaments were mapped from the imagery of the Utah-Nevada study area in the Basin and Range province of the western United States. Several sets of criteria were used, including minimum length, azimuth, and type of topographic expression. The mapped lineaments were then tested for their correspondence with intrusive outcrops and with the location of mines and mining districts. The following results were obtained:

1. Correspondence of lineaments with intrusions:
   a. Lineaments within intrusions show no preferred azimuth.
   b. Intrusions contain as many mappable lineaments as surrounding rock.
   c. Arcuate lineaments may reflect doming by intrusions but do not point to intrusive outcrops at the center of doming.
   d. Alignments of intrusions do not follow any single recognizable lineament.
   e. Intrusions in Nevada may have a linear distribution which is not necessarily related to the Basin and Range outcrop pattern.
2. Correspondence of lineaments with mines and mining districts:
   a. Alignments of mining districts do not lie along any single mappable lineament.
   b. Mines do not appear to be preferentially located along lineaments or lie on intersections of lineaments mappable from Landsat.
   c. Mines do not appear to be preferentially located along lineaments of any particular azimuth.
   d. There does not appear to be any consistancy in the metals produced by mines along a single lineament.
   e. Lineaments are rarely mappable across mining districts, but do appear to separate blocks of mineralized crust from barren crust within the ranges of the Utah-Nevada study area.

f. Lineaments which are parallel to the mineralized structures within a mining district are relatively short and not mappable across the district.

The longest and most persistent sets of lineaments mapped within the Utah-Nevada study area include the Tertiary-Quaternary Basin and Range boundary fault system.

The general lack of correspondence that was found between lineaments and intrusions or mines and mining district suggest that:

1. There may be only random correlation, or
2. The lineaments which may have controlled emplacement of the intrusions and mineralization in the Basin and Range province may not now be visible on Landsat imagery as continuous linear features. Tectonic activity may have caused such lineaments to be overprinted or displaced by younger structures.

DRAINAGE PATTERN STUDIES:

It was not possible to identify intrusions on Landsat imagery by the drainage patterns visible on the imagery. The slope and relief had as much or greater influence on the visible drainage patterns as lithology.

DRAINAGE SLOPE STUDY:

Drainage slope types identified from U-2 imagery could not be used to identify intrusive rock from surrounding country rock. Neither cross stream profiles nor interstream ridge profiles appear to show any systematic relationship to rock type. Since the U-2 imagery showed no positive results, and because the slopes are less clearly discernable on Landsat imagery, no detailed slope studies were made from Landsat imagery.

TONAL AND TEXTURAL CONTRAST STUDY:

No way was found to systematically distinguish mineralized rock from the surrounding rock on Landsat imagery by inspection of tonal and textural contrast with microscope and the human eye.

DRAINAGES AS A POSSIBLE REFLECTION OF LINEAMENTS

Drainages in the vicinity of the Battle Mountain Eureka special study area when statistically compared show a concentration in 3.2-6.4 km (2-4 mi)

length class in the northeast quadrants of mineralized areas.

Drainages show only a weak correspondence to regional geology and show little obvious regard for bedrock control.

Drainages depicted on the 1:250,000 AMS base maps showed considerably less density relative to Landsat, and no azimuthal preferences when mineralized and non-mineralized areas were compared. Drainage studies may prove a useful adjunct to Landsat in northwest and southeast quadrants where lineament suppression occurs due to scan direction.

BASALT IDENTIFICATION ON LANDSAT

Basalts cones and flows whichare often identifiable on Landsat may occur in alignments which appear to be colinear with igneous intrusive bodies. The latter are often difficult to identify on Landsat but may be associated with mineral deposits. Basalts thus appear to have potential for the indirect identification of alignments of mineral deposits.

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INTRODUCTION

A. Purpose of Study

The purpose of this study is to establish possible criteria for using Landsat multispectral imagery, in conjunction with airborne remote sensing data, as a practical tool for mineral exploration.

A broad strip across the Basin and Range Province in Nevada and western Utah, which has a high density of mining districts, was chosen for this study. All large active and abandoned mining districts were to be cataloged and a literature search made to identify the mining districts which were originally located by surface manifestations. Available imagery and photographs were to be examined to determine if the reported anomalies can still be observed.

Standard photogeologic techniques have been used in this study. These techniques attempt to identify anomalous geologic, structural or geomorphic features which can be used to identify intrusions and areas of mineralization. Such linear, tonal or textural features were first mapped in test areas without reference to known geology, and then related to the mapped geology of the test area to verify their usefulness.

Using these features, a number of hypotheses under consideration by economic geologists for the localization of ore deposits in the Western United States have been tested. Among these are that:

1. lineaments and intersections of lineaments control the location of mines.
2. northeasterly trending fractures are most likely to be mineralized.
3. doming of intrusions creates radial and concentric fracture patterns which might be used to locate intrusions and related mineralization.
4. alignments of mines or igneous rock outcrops are controlled by single lineaments.
5. since drainage patterns are strongly influenced by lithology, they may show distinctive patterns over intrusions and be used to identify the intrusions.
6. similarly, drainage slopes across intrusions should show distinctive profiles.

B. Study Area

The area chosen for this study is shown on Figure 1. The Utah-Nevada Study area is a portion of the Basin and Range Province in western Utah and Nevada. The area was chosen because it has a high density of metal mining districts, and there is a large body of published literature available.

Utah-Nevada Study Area

a. Location: The Utah-Nevada study area is located between the Sierra Nevada Mountains on the west and the Wasatch Mountains on the east. It is approximately 800 km (500 mi) long and 200 km (135 mi) wide.

b. Physiography: The Basin and Range Province is an area of generally parallel north-trending ranges and closed intermontaine sedimentary basins. The ranges have been formed by block-faulting and tilting of folded and faulted Precambrian and younger sediments and volcanics. Stewart (1971) describes the province as a system of horsts and grabens produced by deep-seated extension. Plate 1 is a Landsat mosaic of the Utah-Nevada Study area; Plate 2 shows the locations and names of the ranges. Approximately one half of the region is covered by Quaternary basin deposits.

c. Summary of Geologic History*

Precambrian: Western Utah and eastern Nevada were part of the Beltian orogenic belt which extended from Arizona to Alaska. Many tens of thousands of feet of Precambrian sediments were tilted, faulted, bevelled, and overlain by Cambrian sediments.

Paleozoic: Throughout the Paleozoic, the western part of North America was split into two geosynclinal basins, a miogeosyncline in western Utah and eastern Nevada, and a eugeosyncline in western Nevada. The boundaries shifted somewhat from one period to another, but the overall relationships remained fairly constant. The miogeosynclinal rocks are predominantly carbonates with relatively little metamorphism; the eugeosynclinal rocks are dominantly siliceous volcanic material, deposited from upper Cambrian through the Cretaceous, highly metamorphosed and intruded by masses of younger igneous rocks.

A northerly trending band of transitional rocks follows the boundary between the miogeosyncline and the eugeosyncline across central Nevada. This region was a geanticline and the locus of the Antler orogeny in

*Eardley, 1962; Hinze, 1973

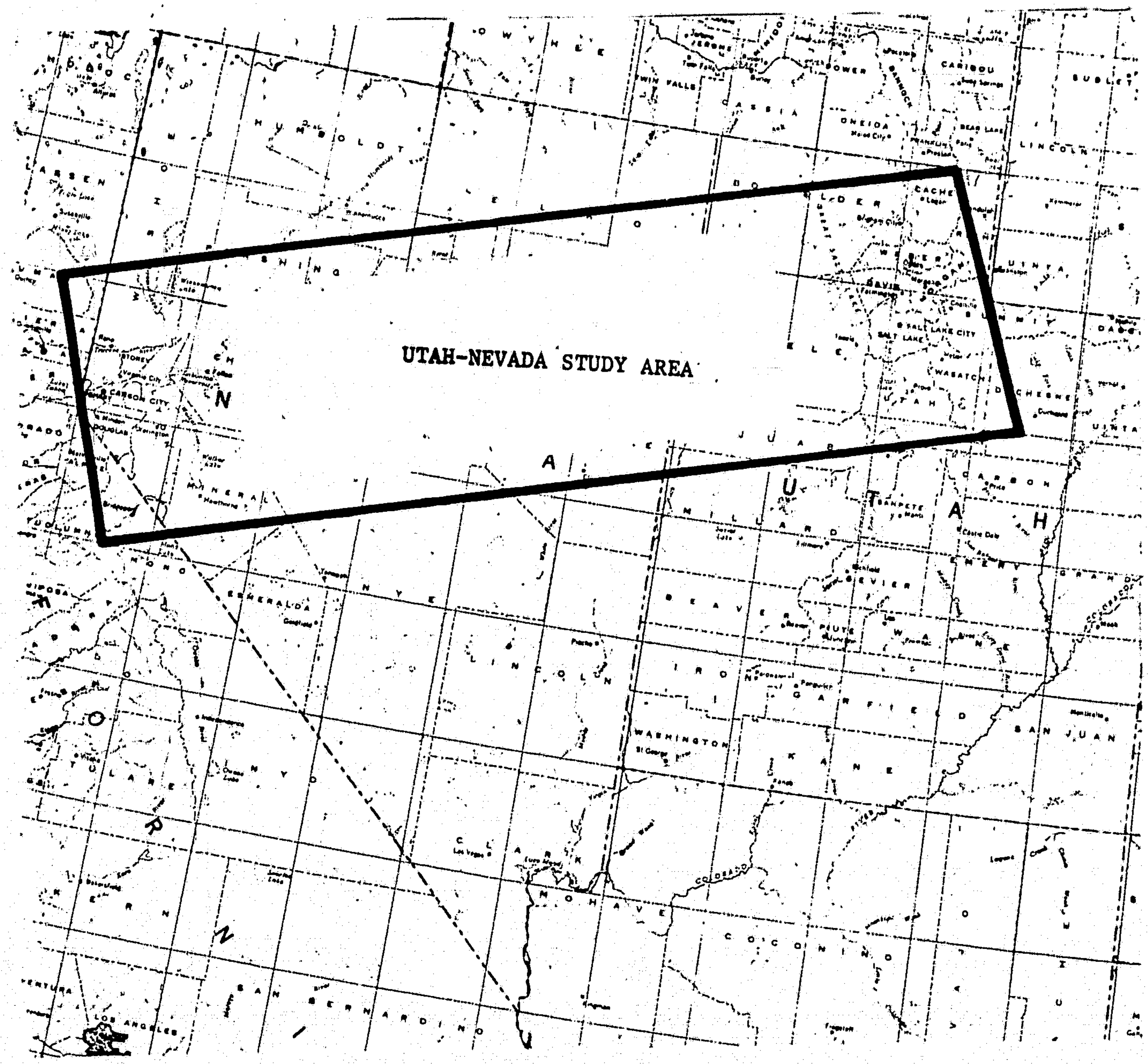


Figure 1: Location of Utah-Nevada Study Area

late Devonian time (Nolan, 1943). At the end of the Devonian, the western eugeosynclinal rocks were thrust eastward over the eastern carbonates. The geanticline was eroded and its place taken by narrow straits and embayments during the rest of the Paleozoic. To the west of the Antler orogenic belt, younger, predominately siliceous rocks rest unconformably on the eugeosynclinal sediments; to the east, these younger rocks interfinger with the late Paleozoic carbonate rocks. The Paleozoic terminated with extensive Permian volcanism.

Mesozoic: Central and western Nevada underwent orogenesis throughout the Mesozoic; the eugeosynclinal trough continued to receive sediments through the Triassic and Jurassic, with uplift and thrusting in late Jurassic.

During the Mesozoic, the region east of the Wasatch line, which had been uplifted relative to the geosynclinal basin to the west, was downdropped and very deep basins east of the line were filled with debris from the late Mesozoic areas of uplift in western Utah. In central and eastern Nevada and adjacent parts of Utah, late Mesozoic eastward decollement-type thrusts were intruded by Tertiary igneous rocks. This thrusting is considered to be on a very large scale and was followed by the Laramide (Cretaceous - early Eocene) thrusting toward the Wasatch line in the eastern portion of the study area.

Basin and Range faulting was initiated in the early Cenozoic as the Wasatch Fault became active and the shelf area to the east was once more uplifted relative to the west. In western Utah and across Nevada, block faulting created northerly trending mountain ranges separated by alluviated basins. This structure is discordant with the complex, highly folded and faulted internal structure of the ranges. All formations, from the Precambrian to the Recent, were affected by this tectonism.

d. Tectonism: The Basin and Range Province has been an area of repeated tectonism. It has been seismically active throughout the Cenozoic and is active today (Smith and Sbar, 1975).

C. Data Sources

1. Landsat and other imagery

Nine inch by nine inch black and white transparencies of Landsat imagery were compared under a microscope to select the cloud-free frames

and bands having the best resolution, definition, and contrast. 1:250,000 and 1:500,000 scale prints were made of this imagery, and a 1:250,000 scale mosaic was made of the entire study area (see Plate 1). This mosaic was used in several of the studies. A list of the Landsat frames used is given in Appendix B.

The flight paths of the U-2 imagery used in this report were located on the mosaic for ready reference.

The 1:1,000,000 Landsat transparencies were used in studies requiring more careful comparisons of tones and textures than is possible using the prints. Repeat coverage makes it possible to verify features as related to geologic rather than ephemeral origin.

U-2 overflights of portions of the study area provided color stereographic pairs for more detailed study of the mining districts as well as drainage pattern analysis, slope shape studies, and tonal and textural studies.

2. Geologic Maps

1:250,000 scale geologic maps are available for Utah (Stokes, 1963; Hintze, 1963) and for most of the counties of Nevada, as well as a 1:500,000 scale preliminary geologic map of Nevada (Stewart and Carlson, 1974). These maps were used for direct comparison with the imagery of the same scale.

3. Mining District Information

a. List and locations

Mining district information was collected prior to this study and recorded on United States Geological Survey Commodity Resources Information Bank (CRIB) forms.

Data for the mines and mineral districts were obtained from various published sources, including the Utah Geological and Mineralogical Survey publications and maps, the Nevada Bureau of Mines and University of Nevada publications and maps, the United States Geological Survey publications and maps, and the general literature. Army Map Service $1^{\circ} \times 2^{\circ}$ topographic sheets (1:250,000 scale) were used as base maps for the compilation of mine locations and other pertinent data. Maps of the Mining Districts and mineral deposits of Nevada and Utah prepared by C. A. Mardirosian (1974) have proved very useful.

An overlay of the locations of the mining districts was prepared and is shown overprinted on the Landsat Mosaic on Plate 1. Much

more detailed local overlays, showing locations of mines and prospects within the mining districts, were used as working sheets for relating locations of mines to lineaments.

A list of the mining districts (Appendix B) was prepared. The 45 districts for which more detailed information was assembled on CRIB forms are indicated with a star; those mining districts with a reported production of more than $1,000,000 have been underlined.

b. Definition of mining district

"Mining district" is a political rather than scientific term, and includes the arbitrarily defined area which includes one or more mines which have similar metal production or are structurally related. In this report, they are located as a point in the geographic center of the district, as defined for the U.S.G.S. CRIB forms.

The districts can vary in size from less than a square kilometer to hundreds of square kilometers; some mineralized areas, as that in the Central Wasatch Mountains, have been divided into a number of arbitrary districts, but may have a single source of mineralization and history.

4. Spatial relationships of known intrusives to mining districts:

The spatial relationships of mining districts to known intrusive outcrops have been determined from literature sources (Nevada Bur. of Mines maps #30 and #24). A bar histogram (Figure 2) has been constructed to show the number of mining districts within a specified distance from the nearest outcrop of intrusive origin.

The areas of individual intrusions were measured and compiled along with other mining district location data as shown in the summary table below:

Nevada, North of 37° Latitude

Total area of Nevada north of 37° latitude	254,119 km^2	
Total area of igneous intrusive outcrop	8,420 km^2	
Total number of metal mining districts	325	
Total number of districts on intrusions		60
Total number within 2 km of intrusions		90
Total number on, plus within 2 km of intrusions		150

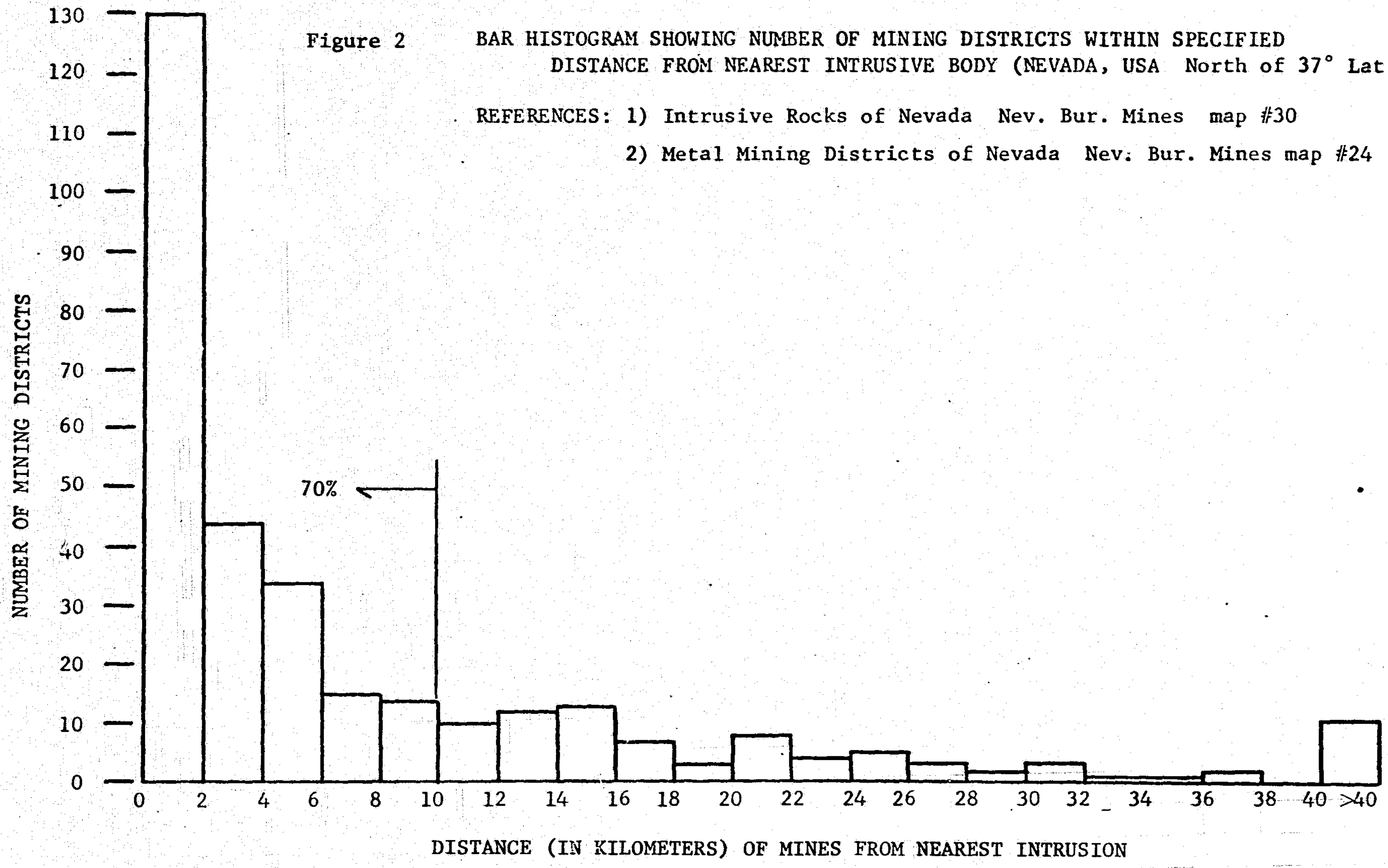


Figure 2 BAR HISTOGRAM SHOWING NUMBER OF MINING DISTRICTS WITHIN SPECIFIED DISTANCE FROM NEAREST INTRUSIVE BODY (NEVADA, USA North of 37° Lat.)

REFERENCES: 1) Intrusive Rocks of Nevada Nev. Bur. Mines map #30

2) Metal Mining Districts of Nevada Nev. Bur. Mines map #24

Intrusive outcrop represents approximately 3 percent of the area of Nevada under study. If a 2 km radius around each intrusion is added, 46 percent of the mining districts fall in about 12 percent of the area under consideration. This regional approach suggests that almost half of the deposits are located on or within 2 km of the intrusive bodies. Based on these results, it is obviously worthwhile to attempt to locate intrusions on Landsat imagery as a guide to mineral exploration in the Basin and Range Province.

5. Mines and Mineralization: Production and Geologic Data

Data from the CRIB forms and other sources were compiled to provide the following information for the 246 mining districts located within the Utah-Nevada study area:

1. Production
2. Host Rock
3. Composition of Associated Intrusives
4. Structural Control of Ore
5. Alteration Types

Frequency charts (Figures 3, 4, 5, 6, and 7) show that 65 mining districts have production greater than $1,000,000. In these, silver is the most important single metal produced, in dollar value, followed by gold, copper, lead, and tungsten. Forty-four of the 65 mining districts produce a gold-silver-copper-lead-zinc suite. Forty-four of the 65 have limestone host rock. Less than half of the mines report hydrothermal alteration. Fifty-five report fracture control of mineralization; 38 report bedding replacement. Forty-nine of the 65 larger mining districts are associated directly with intrusives; 27 of these report quartz monzonite, 17 granite, 7 diorite, and 2 gabbro.

D. Summary of Geologic Techniques

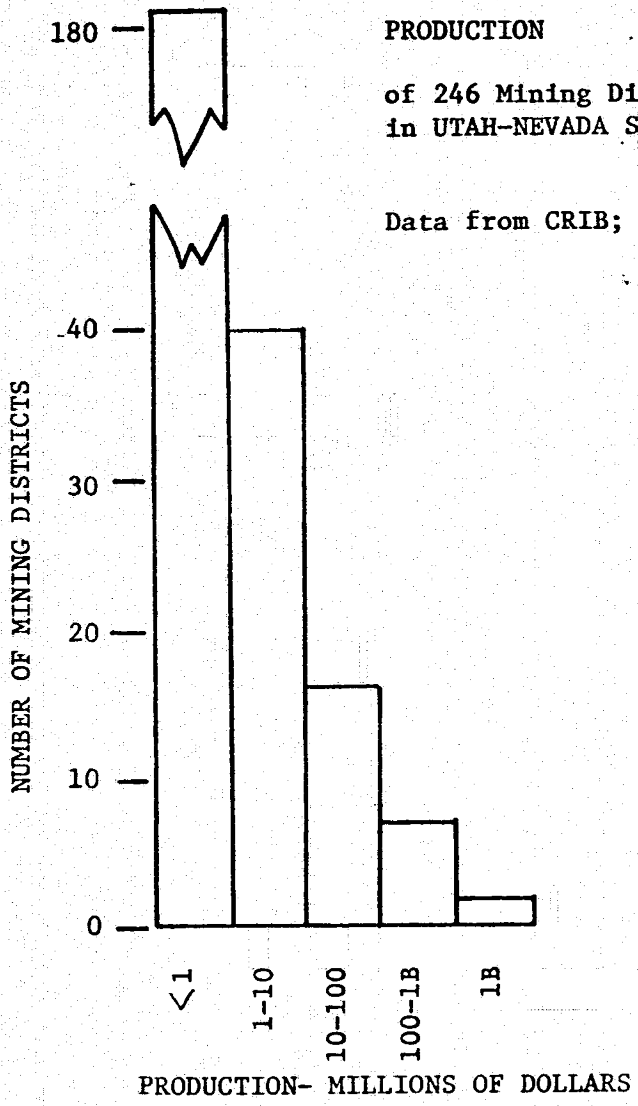
Because the purpose of this report is to test the application of standard photogeologic interpretation techniques to Landsat imagery, a list of the techniques used is given below. The numbers refer to the section of the report in which each technique is applied:

II Lineament studies

1. Lineament analysis

III Geomorphic studies

1. Drainage analysis



PRODUCTION

of 246 Mining Districts
in UTAH-NEVADA STUDY AREA

Data from CRIB; Mardirosian (1974)

FIGURE 3

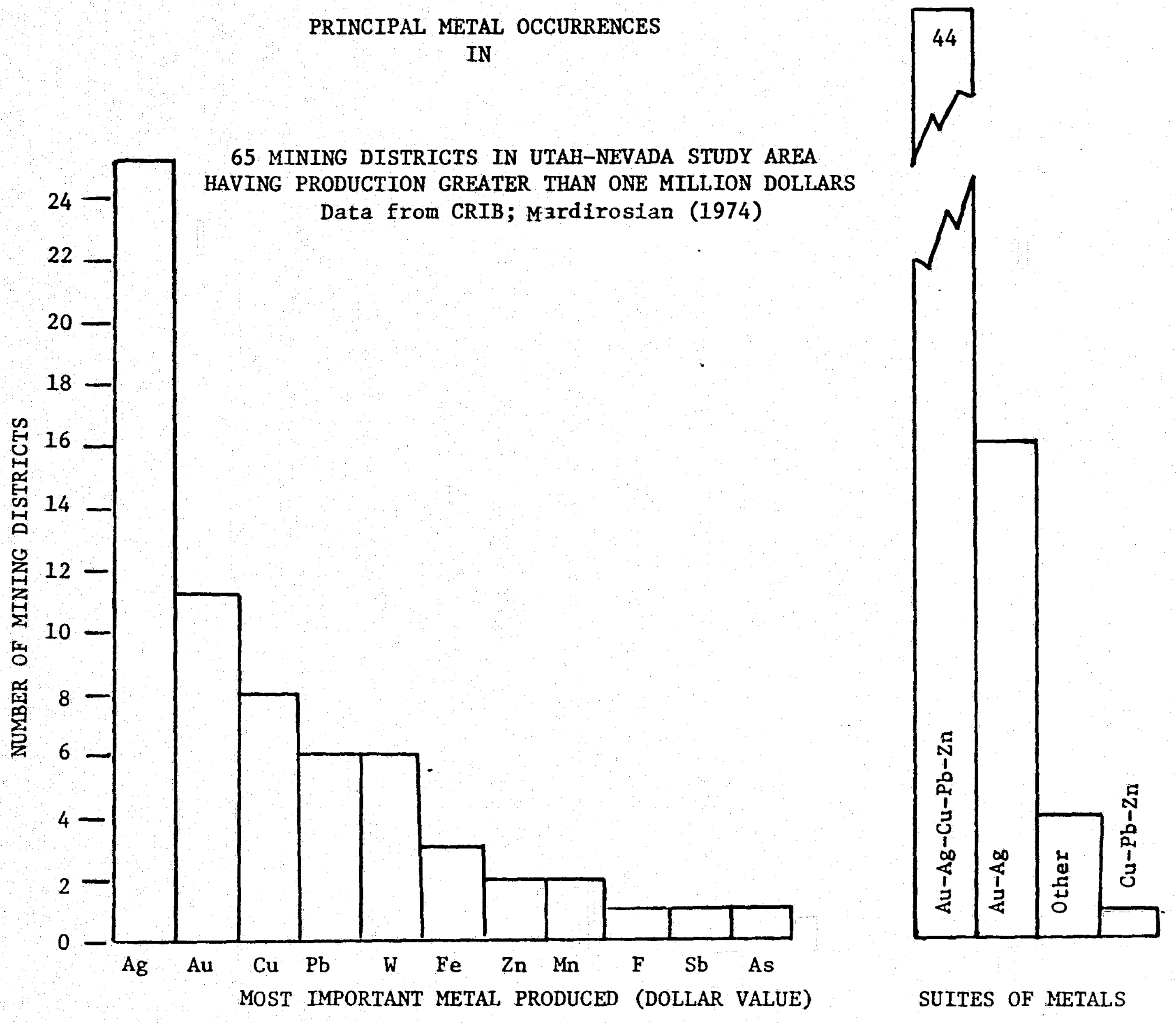

PRINCIPAL METAL OCCURRENCES
IN
65 MINING DISTRICTS IN UTAH-NEVADA STUDY AREA
HAVING PRODUCTION GREATER THAN ONE MILLION DOLLARS
Data from CRIB; Mardirosian (1974)
NUMBER OF MINING DISTRICTS
0
2
4
6
8
10
12
14
16
18
20
22
24
Ag
Au
Cu
Pb
W
Fe
Zn
Mn
F
Sb
As
MOST IMPORTANT METAL PRODUCED (DOLLAR VALUE)
44
Au-Ag-Cu-Pb-Zn
Au-Ag
Other
Cu-Pb-Zn
SUITES OF METALS

FIGURE 4

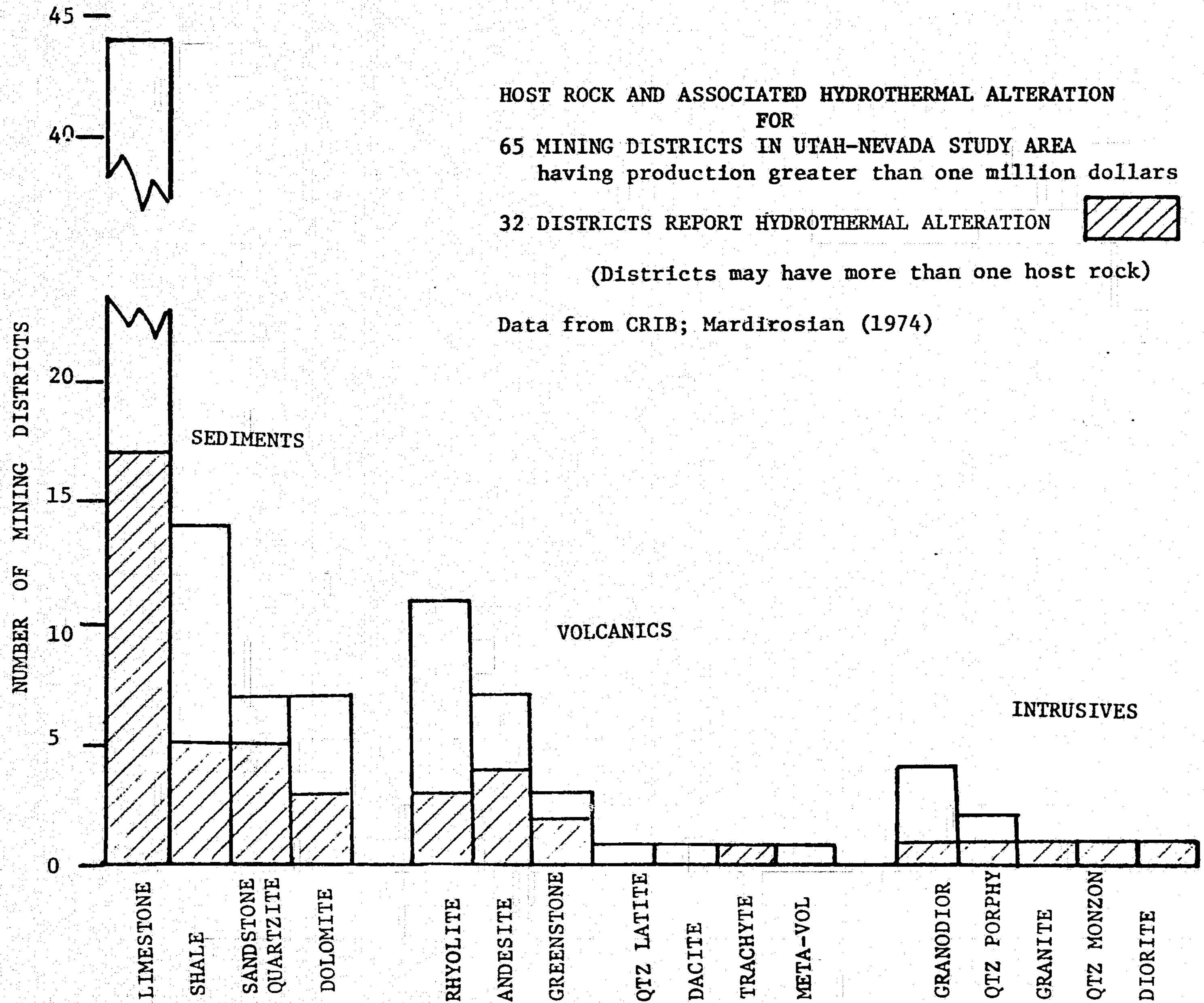
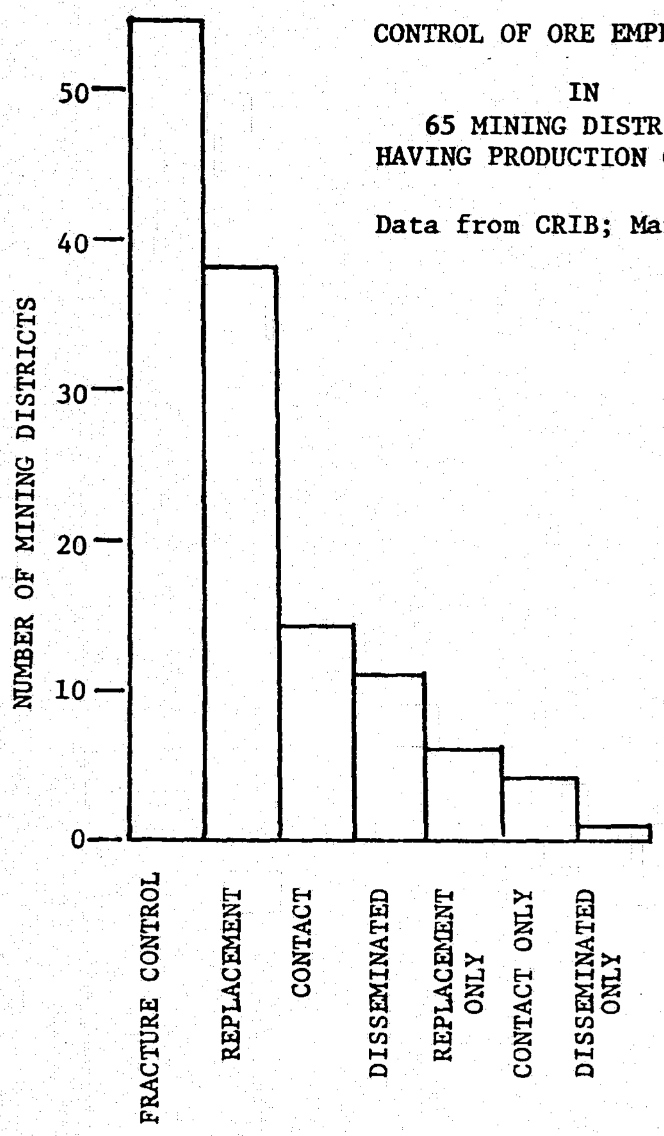

HOST ROCK AND ASSOCIATED HYDROTHERMAL ALTERATION
FOR
65 MINING DISTRICTS IN UTAH-NEVADA STUDY AREA
having production greater than one million dollars
32 DISTRICTS REPORT HYDROTHERMAL ALTERATION
(Districts may have more than one host rock)
Data from CRIB; Mardirosian (1974)
NUMBER OF MINING DISTRICTS
45
40
20
15
10
5
0
SEDIMENTS
VOLCANICS
INTRUSIVES
LIMESTONE
SHALE
SANDSTONE QUARTZITE
DOLOMITE
RHYOLITE
ANDESITE
GREENSTONE
QTZ LATITE
DACITE
TRACHYTE
META-VOL
GRANODIOR
QTZ PORPHY
GRANITE
QTZ MONZON
DIORITE

FIGURE 5



CONTROL OF ORE EMPLACEMENT

IN

65 MINING DISTRICTS IN UTAH-NEVADA STUDY AREA
HAVING PRODUCTION GREATER THAN ONE MILLION DOLLARS

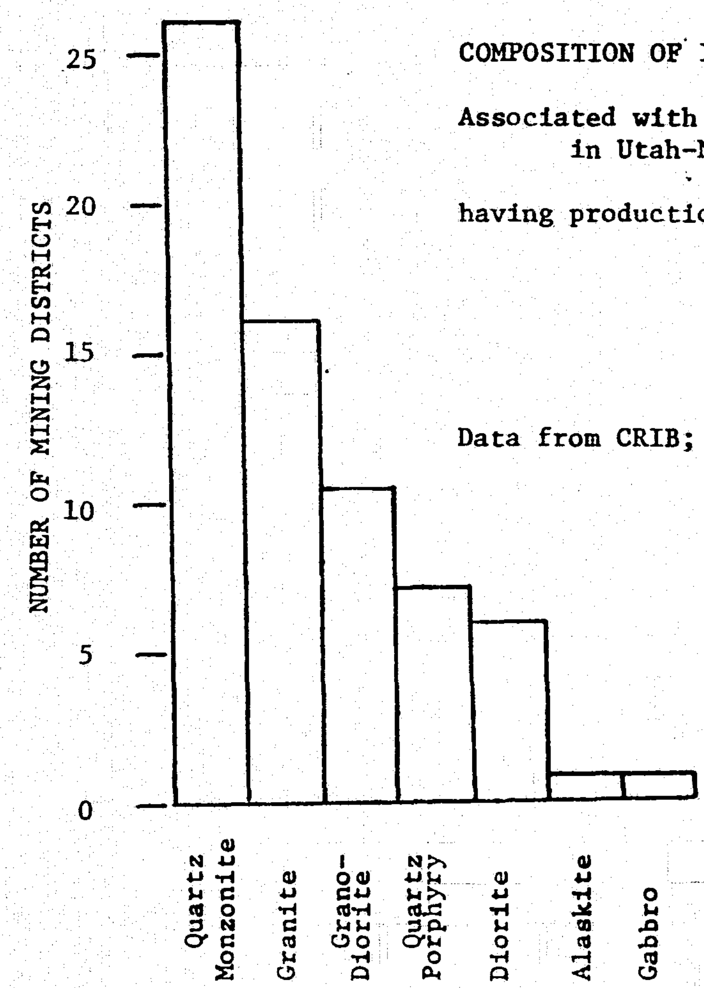
Data from CRIB; Mardirosian (1974)

FIGURE 6

COMPOSITION OF INTRUSIVES

Associated with 49 Of 65 Mining Districts
in Utah-Nevada Study Area

having production greater than one million dollars



Data from CRIB; Mardirosian (1974)

FIGURE 7

2. Slope study

3. Tonal and textural study

IV Valley-stream/lineament analysis

V Valley-stream lineament expression on Landsat compared with topographic maps

VI Relationship of basaltic cone and flow alignment to mining districts

1. Tonal analysis and visual comparison of bands

LINEAMENT STUDIES

A. Introduction

This study is designed to test the relationship of lineaments to mining districts in the Utah-Nevada study area. Lineaments are linear features which are readily discernible on Landsat imagery. It is generally accepted that they are related to deep-seated fracturing of the crust and, as such, may provide the plumbing through which mineralizing solutions reach the surface of the earth. (Hobbs, 1911, and many others.)

1. Early History of Lineament Studies

Lineaments were first mapped in Great Britian in the early 19th century by William A. Hopkins (1841) who observed that there was a systematic pattern and distribution of faults and joints, and that these systems maintain remarkably constant azimuths over significantly large areas. He also noted that there is a common tendency toward orthogonal relationships between intersecting sets of fractures. Hopkins proposed an advanced mechanical theory, based on extensive observations, to explain these relationships by structural uplift, and in 1841 produced the first true lineament map.

A French geologist, A. Daubree, in 1879 observed that faults and joints are genetically related to drainages and topographic elements, and used indirect physiographic evidence as well as direct observation to map fractures.

William Herbert Hobbs, an American geologist, studied the relationships of fracture systems and drainages in New England and in Europe at the beginning of the twentieth century. He found that drainages appeared to be controlled by the underlying systematic fracture patterns. In 1911 he published a summary of his work and all that was known about lineaments at that time (Hobbs, 1911). In this work he included the concept of orders of fractures within the same set or system, and the tendency to unit spacing of fractures within a given set. He also developed the concept of the fracture field to describe large but limited areas within which a uniform fracture set direction is found. Several such fields may overlap; he also found disorderly fracture fields which he considered to show the effects of strong local structural events superimposed on the more regional structural pattern which he considered to be a fundamental basement controlled fracture pattern. He noted a general tendency toward orthogonal

relations between intersecting sets, and found that there is a nearly universal persistence of four prominant fracture sets having N-S, E-W, NE and SE trending azimuths.

Since the publications of Hobbs, and especially with the advent of aerial photography and satellite imagery, the study of lineaments has received increasing attention, but there has been little agreement as to what the lineaments are. Criteria for their recognition have not been clearly established, and as a result, there has been confusion and doubt as to their distribution and meaning. O'Leary and others (1976) have traced the history of the useage of the term "lineament" and have proposed a more stringent definition. Although a large body of literature now exists on lineaments, the following discussion is restricted to the proposed relationship of lineaments to ore deposits.

2. Lineaments and their relationships to mining districts

<u>Lineament control of the location and emplacement of many ore deposits</u>

Jerome and Cook (1967) found that structure is the only common denominator for the localization of ore deposits. They found persistent clustering and alignment of the mining districts in the Western U.S. with close temporal and spatial relationships of structure, igneous activity, and ore deposition.

Hodder and Hollister (1974) in a discussion of the relationships of lineaments and ore deposits, express the generally held idea that "the lineaments are major faults along which fluids ascend from depth and deposit metals in response to declining pressure and temperature and reaction with the enveloping rocks."

<u>Age of Lineaments related to mining districts</u>

Hodder and Hollister (1974) have found that lineaments are of value in locating hydrothermal mineral deposits only in stable shield or craton regions where there has been igneous activity along post-orogenic tension fractures. Massive base metal sulfide deposits lie along lineaments which are post ore and thus cannot be passageways for the ore forming fluids. They find that lineaments are, therefore, likely to be of little if any value in the search for mining districts in the tectonically active Basin and Range Province.

<u>Intersections of lineaments as control of mineralization</u>

Mayo (1958) and Wisser (1958) found the spatial distribution of ore

deposits in the southwestern United States to be related to four lineament trends and to their intersections (Wisser, p 40). Kutina (1974) has drawn empirical prospecting grids, based on this concept, which he believes are part of a world-wide basement fracture system. Kutina shows (on a gross scale) that the large endogenic ore deposits are found at the intersections of deep basement fracture patterns which belong to N-S, E-W, NE-SW and NW-SE sets which are equidistantly spaced. He finds this relationship holds at different scales, including the distribution of mines within a mining district, the distribution of mining districts within a region, and their distribution on a continental and global scale.

Wertz (1974) however, notes that in the Northern Cordillera of North America, mines occur 10 to 50 more miles from the intersections of major lineaments.

NE trending fractures as control of mineralization

Stokes (1968) made a statistical study of the relationships of mapped faults on the Geological Map of Utah (Stokes, 1963; Hinze, 1963), with the mining districts in the eastern Great Basin. This study found that stronger mineralization in this region is associated with northeasterly to easterly trending faults. Stokes also concluded that most ore deposits are not genetically related to the northerly trending mountain blocks in the Great Basin but "are related to relatively obscure fractures that cut diagonally across them. This being true, ore deposits may be expected to occur in the depressed, unexposed blocks with about as much frequency as in the exposed areas."

3. Definitions and Descriptions of Lineaments

a. Definitions

There has been considerable interest in lineaments since the advent of aerial photography and high altitude imagery, and some confusion as to the meanings of the terms "lineaments" and "linear" as used in the literature. This report follows the useage originally introduced by Hobbs (1911) and redefined by O'Leary and others (1976, p 1463): a lineament is essentially a geomorphic feature, a "mappable, simple or composite linear feature of a surface, whose parts are aligned in a rectilinear or slightly curvilinear relationship

and which differs distinctly from the patterns of adjacent features which presumably reflects a subsurface phenomenon." Linear is used only as an adjective. "Line" and "alignment" refer to non-geologic features.

b. Description of Lineaments

Hobbs (1911) described lineaments as mappable linear features

1) which have geomorphic expression (generally topographically negative);
2) are composite, either segmented or complex;
3) are characterized by alignment in a single direction which may or may not conform with the regional structural trends;
4) are straight or slightly curved;
5) are regional in extent, differing from patterns of adjacent features;
6) are scale related;
7) and are commonly or probably related to structural discontinuities.

With the advent of aerial photography, it was noted that many linear features could be discerned on photographs which were not readily discernible from the ground. Lattman (1958) describes photogeologic lineaments as those linear features observed on aerial photographs as alignments of stream segments, topographic features, and soil or vegetational tonal anomalies which are continuous for more than one mile in length. These may be controlled by faults or zones or joint concentrations. They tend to cross structural, temporal, and physiographic boundaries.

Short (1973) found the major contribution of synoptic Landsat imagery to be its exceptional ability to show large structural features. In spite of its limited resolution, approximately 100 meters, the imagery records numerous heretofore unrecognized linear features, many of which are faults, joints, or fracture zones.

These linear features tend to be scale related; on higher resolution photography or on larger scale imagery, a linear feature that appears clearly defined on Landsat degrades into a zone of more scattered and relatively short linear features.

Hobbs (1904) pointed out that "lineaments which may appear rectilinear on maps may be so only in proportion as the scale of the map is small."

c. Validity of Lineaments Located on Landsat Imagery

Isachsen (1973) has field checked lineaments located on Landsat imagery in the Adirondack Mountains in the State of New York, and has found that only 30 to 40 percent of these correspond to mappable structural features. A small percentage of the lineaments were alignments of non-geological features; the rest were of uncertain orgin.

d. Width of Lineaments

In this study, lineaments are treated as linear features having no definite width. As seen on the imagery, the width is variable and uncertain. In Section II-D-1, a width of 2 km is assumed for calculating the area covered by the lineaments.

4. Selection of Lineaments: number and reproducibility

Two problems inherent in the selection of lineaments are 1) the number which may be selected, and 2) the reproducibility of those which are selected. There is a wide variation in lineament mapping by different investigators, both in the numbers and length of lineaments mapped and in their locations and azimuths.

a. Number

A great number of lineaments are normally visible on any Landsat (or other) imagery. It is possible to locate so many lineaments that a map of their locations becomes a dense mass of intersecting lines. The actual number of lineaments selected then becomes a function of the skill and enthusiasm of the operator, the resolution and contrast of the imagery, and the amount of time that the operator has at his disposal.

b. Reproducibility

Tests show that two operators, or the same operator after an interval of several months (Clinton and Kelley, 1960), find only a very small (5 to 10 percent) correlation of lineaments selected from the same imagery. The actual lineaments selected thus represent a sample of the possible population of lineaments, and any of them

may be as valid as other possible lineaments chosen at random by another operator.

In this report, an attempt was made to reduce variability among operators mapping lineaments by setting up limited criteria for the selection of the lineaments. Possible limitations are the length of lineaments, the azimuth, and types of geomorphic expression considered valid as indicators of lineaments (i.e., drainages, etc.). The criteria used for selection are explained in each section of the report to which they apply. A summary is given below:

Summary of criteria used for the selection of lineaments:

Section II-B-2, and Section II-D-2

Limited azimuth sets: lineaments are all natural linear features with 1) azimuthal range $\pm 10^{\circ}$ (number of sets specified for each study), 2) minimum length of 2 km, 3) no restriction on type of topographic expression.

Section II-D-1-c

Arcuate lineaments: alignments of natural features which form segments of regular curves, at least 75 percent topographic expression.

Section II-D-2-a

Lineaments parallel to alignments of intrusives: sets of all natural linear features parallel to (or within 5° of) alignments of intrusives as described in the study.

Section II-B-1

Random azimuth sets: all natural linear features which 1) are greater than 5 km in length, 2) have geomorphic expression for more than half their length, 3) cross divides and ridges (to avoid simple consequent drainages), 4) are visible to at least two operators.

To avoid undue concentration of linears in any one area, the study area was broken into smaller sub-areas and a limited time allowed for alineament search in each sub-area.

5. Outline Summary of Lineament Studies in This Report

A series of studies of lineaments were made to determine the answers to specific questions. The following is a list of questions

asked and the part of the ensuing report that deals with that question:

II-B-1-b Is there a correlation between lineaments and the locations of mines?

c Do more mines lie on lineaments of a certain azimuth?

d Does a lineament provide a common source of metals for those mines that lie along it?

e Do as many mines fall on mapped faults as on lineaments?

II-B-2-b Do lineaments connect mines and mining districts?

c Do lineaments bound blocks of mineralized crust which define mining districts within a mountain range?

II-B-3 Can lineaments which are related to the mineralization be found as single lines across a mining district?

II-C-1 What geologic features are found at the intersections of lineaments?

2 What is the effect of scale on the appearance of a lineament?

3 What is the appearance of a lineament on the ground; what special features (mines, springs, faults, geologic boundaries) are found on or along it?

II-D-1-a Are lineaments as continuous across intrusions as across the surrounding country rock?

b Are there significantly greater numbers of NE or NW trending lineaments across intrusions?

c Do arcuate lineaments reflect doming of crust by intrusions?

II-D-2-a Is there a correlation of lineaments with alignments of intrusion?

b Is there a linear control of intrusions in Nevada?

c Is this linear distribution a function of the Basin and Range outcrop pattern?

B. Relations of Lineaments to Mines and Mining Districts

1. Random Azimuth Lineament Study

a. Selection of lineaments

Over 200 lineaments were located on the 1:250,000 scale Landsat Mosaic of the Utah-Nevada study area, using the following criteria:

1. Each must be more than 10 km in length.
2. Each must have at least 50 percent topographic expression by length.
3. Each must cross ridge crests (divides) to insure its not being a simple consequent drainage.
4. Each must be obvious to at least two independent observers.
5. A limited and fixed time is allowed for selection of lineaments for each area covered by one AMS sheet (1^{o}x 2^{o} area, approximately 19,000 km^2), to minimize undue concentration of time and effort on any single area.

The lineaments were located on the imagery, then plotted on United States Army Topographic Command Maps (AMS sheets). They were then traced on transparent mylar overlay sheets to avoid distracting background (Plate 4, location of random azimuth lineaments across study area).

b. Control of mines and mining districts by lineaments

To test the hypothesis that mine locations are controlled by lineaments and lineament intersections, the lineaments, plotted on AMS sheet overlays, were directly compared with the locations of the mines and mining districts which had been plotted on separate mylar overlays of each AMS sheet in the study area. The number of mines on each AMS sheet were counted, and the area of the actual portion of each AMS sheet lying within the study area was measured in km^2. The number and length of lineaments were determined, as well as the number of lineament intersections.

This information is shown in Table 2 (A & B). The area for the lineaments was computed by assuming a width of 2 km. The percent of the total area covered by lineaments was computed (Column 5) and the percent of the mines on each AMS sheet which fell on the lineaments (Column 8). The ratio of percent mines over percent area was calculated (Column 9). On three AMS sheets (the contiguous Tooele, Delta, and Price sheets) this ratio was anomalously high.

To check the possibility that this high ratio might be the effect of the very small outcrop area on the Tooele and Delta AMS sheets, which include large portions of the Great Salt Lake Desert and the Sevier Desert, the total outcrop area for these and seven other AMS sheets (Price, Salt Lake, Millett, Reno, Tonopah, Lovelock, and Ogden) was

AMS SHEET	1 Total area km^2	2 Number of lineaments	3 Total length of lineaments	4 Lineament area (km^2) (2 km width)	5 Lineament % total area (4/1)	6 # of mines located on AMS	7 # mines on lineaments (within 1 km)
Price 1/4	4760	5	80 km	160 km^2	3.5	14	5
Salt Lake 1/2	9390	17	440	880	9	49	3
Tooele	18770	7	300	600	3	21	6
Delta 1/2	9525	5	100	200	2	26	5
Wells	18495	3	60	120	1	65	0
Lund	19330	13	220	440	2	14	1
Ely	19050	35	1100	2200	12	53	17
Elko	18770	17	700	1400	8	19	3
Millett	19050	29	680	1360	7	20	2
Winnemucca	18770	14	710	1420	8	23	4
Reno	19050	34	1180	2360	12	69	16
Tonopah	19330	25	770	1540	8	74	13
Lovelock	18770	19	780	1560	8	106	5
Walker Lake 1/2	9665	5	180	360	4	113	2
Brigham City	18495	1	82	164	1	10	0
Ogden 1/2	9250	5	201	402	4	6	1
Total	241220 km^2	228	7400	148,000 km^2		666	82

TABLE 2: Relationships of random azimuth lineaments and mines in the Utah-Nevada Study Area (A)

8 % of mines located on lineaments (7/6)	9 % mines / % area (8/5)	10 Number of lineament intersections	11 Total mines on intersects	12 Actual outcrop area	13 % outcrop	14 Lineament % outcrop (4/12)	15 % Mines (8) / % outcrop (14)	16 Number of lineaments with mines within 1 km
36%	10.28	2	1	4085 km^2	86%	4%	9.0	1
6	.67	8	0	6978	75	13%	.46	2
29	9.67	4	2	3721	20	16%	1.81	3
19	9.5	2	0	3230	34	6%	3.17	2
0	0	0	0					0
7	3.5	1	0					2
32	2.7	32	0					9
16	2.0	17	0					1
10	1.4	19	0	9093	48	15	.67	11
17	2.1	10	1					9
23	1.9	35	2	8906	47	26	.88	14
18	2.25	23	6	10406	54	15	1.20	7
5	.63	11	0	9625	51	16	.33	7
2	.50	1	0					3
0	0	0	0	-	-	-	-	0
17	4	0	0	6850	73	6	2.83	0
		165	12					71

Table 2 : Relationships of random azimuth lineaments and mines in the Utah-Nevada Study Area (B)

(continued from Table 2 (A))

measured (Column 12), and the ratios recalculated (Column 15).

The recalculated ratios for the Tooele and Delta sheets were comparable to the ratios for the other AMS sheets, with the exception of the Price AMS sheet. This sheet has a much higher percent of outcrop area, as does the Salt Lake sheet to the north.

Both the Salt Lake and the Price AMS sheets include the eastern edge of the Basin and Range province, and the Wasatch Front. The Salt Lake AMS sheet includes a portion of the Central Wasatch Mountains and the Unita Mountains; the Price sheet includes the Unita Basin, a portion of the Colorado Plateau province.

It is possible that this difference in province may account for the anomalously high ratio for the Price AMS sheet area; the Tertiary sediments of the Unita Basin are mapped as outcrop, but may have the same influence on the mine-lineament relationships as the Quaternary sediments in the deserts and basins of the Tooele and Delta AMS sheet areas.

In summary, of a total of 666 mines located in the Utah-Nevada study area, 37 fall on one of the 228 lineaments, and 80 are within 1 km of a lineament. Two thirds of the lineaments have no mines within 1 km. Only 7 of the lineaments have 2 or more mines on the lineament; only 20 have two or more mines within 1 km.

Only 7 of the 165 lineament intersections are within 1 km of a mine.

From these data, the qualitative conclusion may be drawn that there is little if any control of locus of mineralization by the lineaments selected from Landsat imagery using the criteria given, in the Utah-Nevada study area.

c. Control of mines by a particular azimuthal range of lineaments.

To test the concept that northeasterly trending fractures are more likely to be mineralized than those of other azimuths (Stokes, 1968), and assuming that lineaments are fractures, the plotted lineaments were grouped into classes having azimuthal classes of 20-25^{o}. Of the 80 mines falling within 1 km of the lineaments, the distribution is as follows:

from N 100^{o} to 80^{o} W - 9 mines
N 80^{o} to 55^{o} W - 9 mines
N 55^{o} to 35^{o} W - 16 mines

N 35^{o} to 10^{o} W - 13 mines
N 10^{o}W to 10^{o}E - 5 mines
N 10^{o}E to 35^{o}E - 6 mines
N 35^{o} to 55^{o} E - 6 mines
N 55^{o} to 80^{o} E - 16 mines

This shows a bimodal distribution with a greater number of mines on lineaments having a northwest azimuth (38 mines or 47 percent) than on lineaments having a northeast azimuth (28 mines or 35 percent). It is concluded therefore that northeast trending lineaments in the Utah-Nevada study area do not accord with Stokes findings that fractures in western Utah show preferential mineralization. This may mean that:

1) the ore-bearing fractures do not show up as parts of lineaments as selected in this study, or
2) that too large an area has been considered to make a valid comparison.

d. Lineaments as a common source of metals

To find if several mines along a single lineament show evidence of having a common source of mineralization, as shown by the metal production of the mines, four lineaments from the previous study were located on the Reno AMS sheet. Each of these lineaments has two or more mines within 1 km of the lineament. The metal production of the mines is listed below:

Principal metal production reported

Trend of lineament	1st mine	2nd mine	3rd mine	4th mine
N 60^{o} E	Lead	Copper	Gold	
N 50^{o} W	Gold	Mercury		
N 85^{o} W	Gold	Silver	Silver	Gold
N 45^{o} W	Lead	Gold Tungsten	Gold	

There does not appear to be any consistent metal-type produced along any of the lineaments. This may be misleading if the mines actually produce overlapping suites of metals, of which only one

is reported as being of economic significance. More detailed study of the mineral occurrences within the mines is needed to completely answer this question, but the preliminary results herein given do not suppost common metal production along a particular alignment.

e. Mines on lineaments compared with mines on mapped faults

To find if more mines are located on mapped faults than on the lineaments selected in the previous study, the total length of all mapped faults within the Utah portion of the study area was measured from the Geologic Map of Utah (Stokes, 1963). The area was subdivided by AMS sheets, as in the previous study. The mines on and within 1 km of the faults were counted, using the same mine overlays as in the previous study. A comparison of the results is shown in the following table:

AMS SHEET	Mines on AMS sheet	Length of faults	Mines on faults	Length of Lineaments	Mines on Lineaments
Tooele	21	525	15	300 km	6
Delta	26	1232	7	100	5
Price	14	385	11	80	5
Salt Lake	49	392	14	440	3
Total	110	2534	47	920	19

AMS SHEET	km of fault per mine	km of lineament per mine
Tooele	35	50
Delta	176	20
Price	35	16
Salt Lake	28	147
Average	68	58

There is no consistent preference for location of mines on either mapped faults or lineaments. The average length of fault and lineament per mine is remarkably similar for the Utah area.

2. Limited Azimuth Lineament Study

a. Selection of lineaments

As the lineaments in the initial study do not intersect any

appreciable number of mines, it may be that the initial selection was too limited to find those lineaments which do intersect mining districts and many mines, if in fact such lineaments do exist.

Examination of the locations of the mines and mining districts on the Walker Lake 1:250,000 scale AMS sheet (NJ-11-4), in southwestern Nevada, selected because the area has a high density of mines and available geologic data, showed several north-south alignments of mines and mining districts. Accordingly, all lineaments within 10^{0} of north were mapped. The selection of these lineaments for mapping differed from the initial lineament study in that

1) minimum length was 2 km,
2) all natural linear features within the given azimuth range are chosen; topographic linears are drawn on the map as solid lines, tonals as dotted lines.

b. Lineaments connecting alignments of mines and mining districts

To find if these lineaments actually follow or connect alignments of mines and mining districts, those selected from the 1:250,000 scale Landsat Frame E-1397-18051-5 (selected as explained above) were compared with the mines located on the mylar overlay of the area. Figure 8 shows a section of the Walker Lake AMS sheet overlay, showing locations of mines and lineaments.

These lineaments divide the area into sections from 1 to 30 km wide. Some mining districts (clusters up to 30 mines and prospects) fall between two adjacent lineaments or alignments of lineaments. The lineaments bound rather than intersect the mineralized areas, and in fact, appear to sharply delineate mineralized and non-mineralized areas. It should be noted that these areas are within mountain ranges and have exposed areas of outcrop to either side; that is, the boundaries between mineralized and non-mineralized areas are not range fronts.

The north-south extent of any particular mining district averages about 5 km. Several mining districts aligned in a north-south direction between two parallel alignments of lineaments have a total north-south length of up to 30 km. These relationships show up particularly well in the Pine Nut Range (see (Figure 9), the Garfield Hills, and the Pilot Mountains (Figure 8).

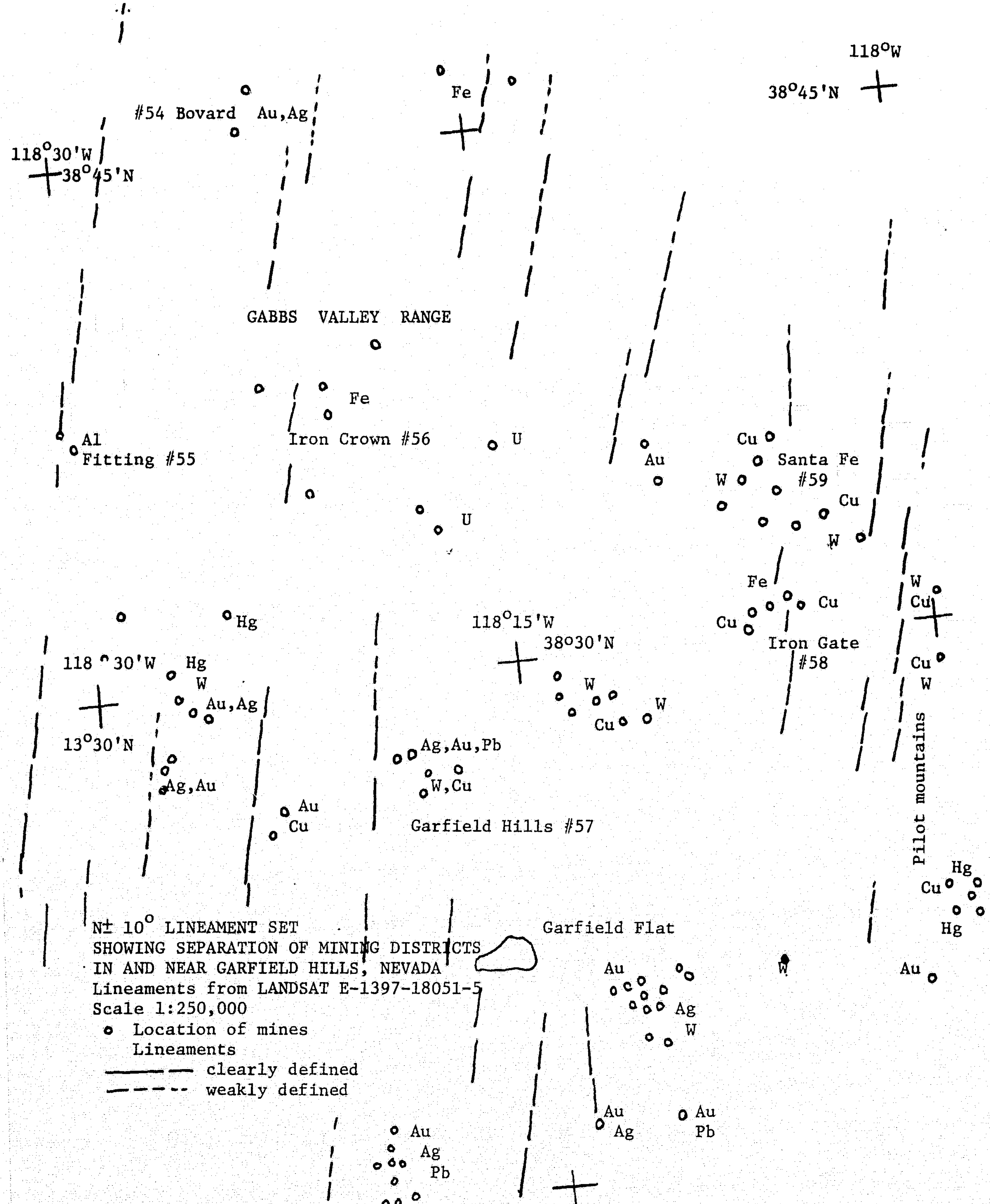


FIGURE 8: LIMITED AZIMUTH LINEAMENT SET

Where lineaments do cross a mining district, they appear to be broken or offset (note the lineaments across the Santa Fe (No. 59) and the Iron Gate (No. 58) on Figure 8).

It is concluded that, within the N $\pm$ 10^{o} azimuthal range, no lineaments were found which appeared to directly intersect alignments of mines or mining districts. Instead, some appeared to bound areas of crust which contain a high density of mines.

c. Lineaments bounding mining districts

To test further the possibility that lineaments bound blocks of crust containing markedly different degrees of mineralization, as evidenced by density of mines, a second set of lineaments was mapped on the same imagery, and using the same criteria as described for the preceding study. The azimuthal range selected was east $\pm$ 10^{o}. This azimuthal range parallels several strong E-W topographic trends across the area under study.

Comparison of these two sets of lineaments (N $\pm$ 10^{o} and E $\pm$ 10^{o}) with the mine overlay shows that the east-west lineaments again tend to bound the areas of mineralization rather than intersect them. Figure 9 shows a portion of the Walker Lake AMS sheet with the two sets of lineaments and the mines. In the Pine Nut Range, west of Walker Lake, a north-south alignment of mining districts is bounded on the east and west by north-trending lineaments, and the districts are separated by the east-trending lineaments. Each district has a different metal production.

These studies suggest that lineaments may bound blocks and bring together blocks having different tectonic and igneous histories. Some of these blocks may be elevated relative to the rest, bringing mineralized rock to the surface (assuming it has been mineralized deeper within the crust). The mineralized blocks occur within the ranges and appear to have moved independently of the Basin and Range faulting.

3. Lineaments Across Mining Districts

The preceding studies indicated that it is unusual to find lineaments which can be traced across a mining district, and when such lineaments are found, they are not obviously related to the mineralization in the

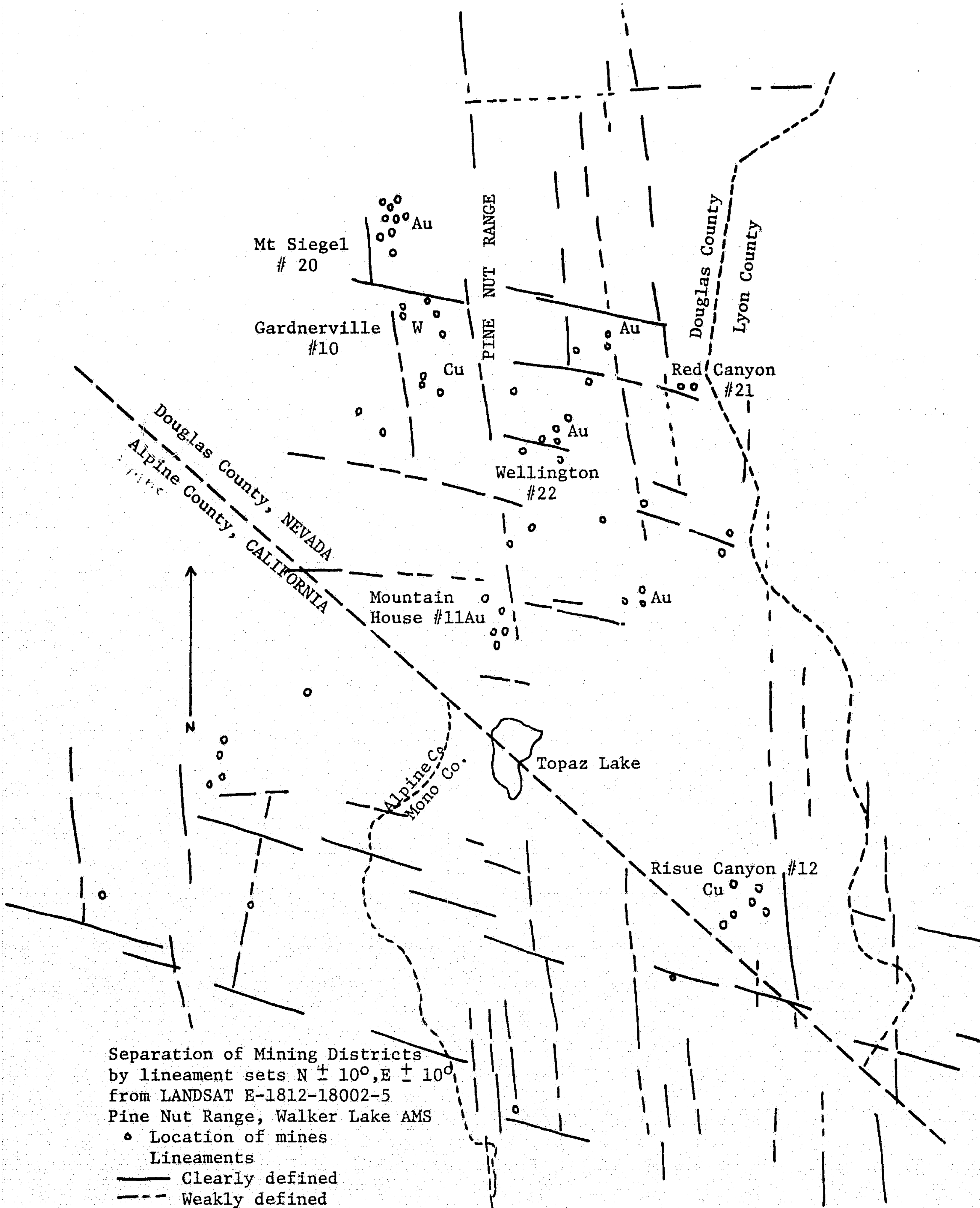


FIG. 9: LIMITED AZIMUTH LINEAMENTS: 2 SETS

district. Those lineaments which can be traced across a district tend to be visible as an alignment of short and somewhat scattered lineaments, rather than continuous linear features.

To find if this is true in other mining districts, in the central and eastern parts of the study area, four areas (Figure 10) were selected for which there is both Landsat and U-2 coverage. Each of these areas has from one to four mining districts, at least one of which has been a very large metal producer.

The areas selected for this study are:

1) Eureka Mining District, Nevada (Number 141), 15 x 20 km.

2) Central Wasatch Mountains, Utah, 25 x 25 km.
   - American Fork Mining District (Number 233)
   - Big and Little Cottonwood Mining Districts, including Alta and Brighton Districts (Number 234)
   - Park City Mining District (Number 237)

3) Oquirrh Mountains, Utah, 20 x 20 km
   - Bingham (West Mountain) Mining District (Number 220)
   - Stockton Mining District (Number 219)
   - Ophir Mining District (Number 221)
   - Mercur-Camp Floyd Mining District (Number 222)

4) Tintic Mountains, Utah, 20 x 25 km.
   - North Tintic Mining District (Number 223)
   - Tintic-Eureka Mining District (Number 224)

a. Selection of lineaments

Lineaments were mapped on Landsat 1:250,000 scale prints and on U-2 color transparency stereo pairs. The lineaments are natural linear features visible as sharp lines or boundaries, more than 2 km in length, and may be identified with drainages, ridges, cliff lines, fractures, outcrop lines, and sharp tonal and textural boundaries.

b. Eureka Mining District, Eureka Country, Nevada

Figure 11 shows the lineament patterns traced from Landsat E-1755-17450 across the Eureka Mining District, and the north-trending anticlinal outcrop of Cambrian sediments, the oldest exposed in the area. All but one of the mines are located in the Cambrian (geology and mine locations from the Geologic Map of Eureka Country,

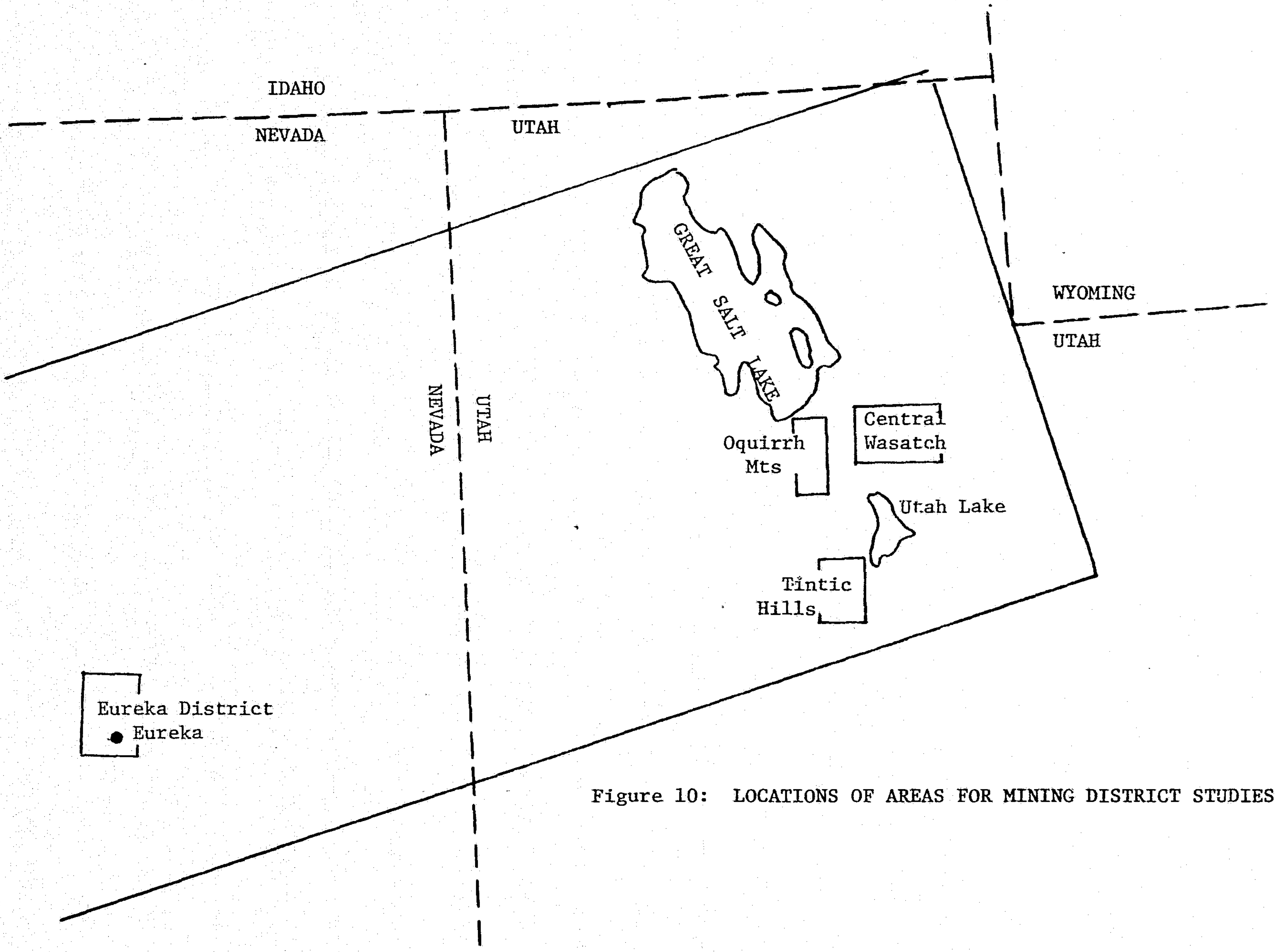


Figure 10: LOCATIONS OF AREAS FOR MINING DISTRICT STUDIES

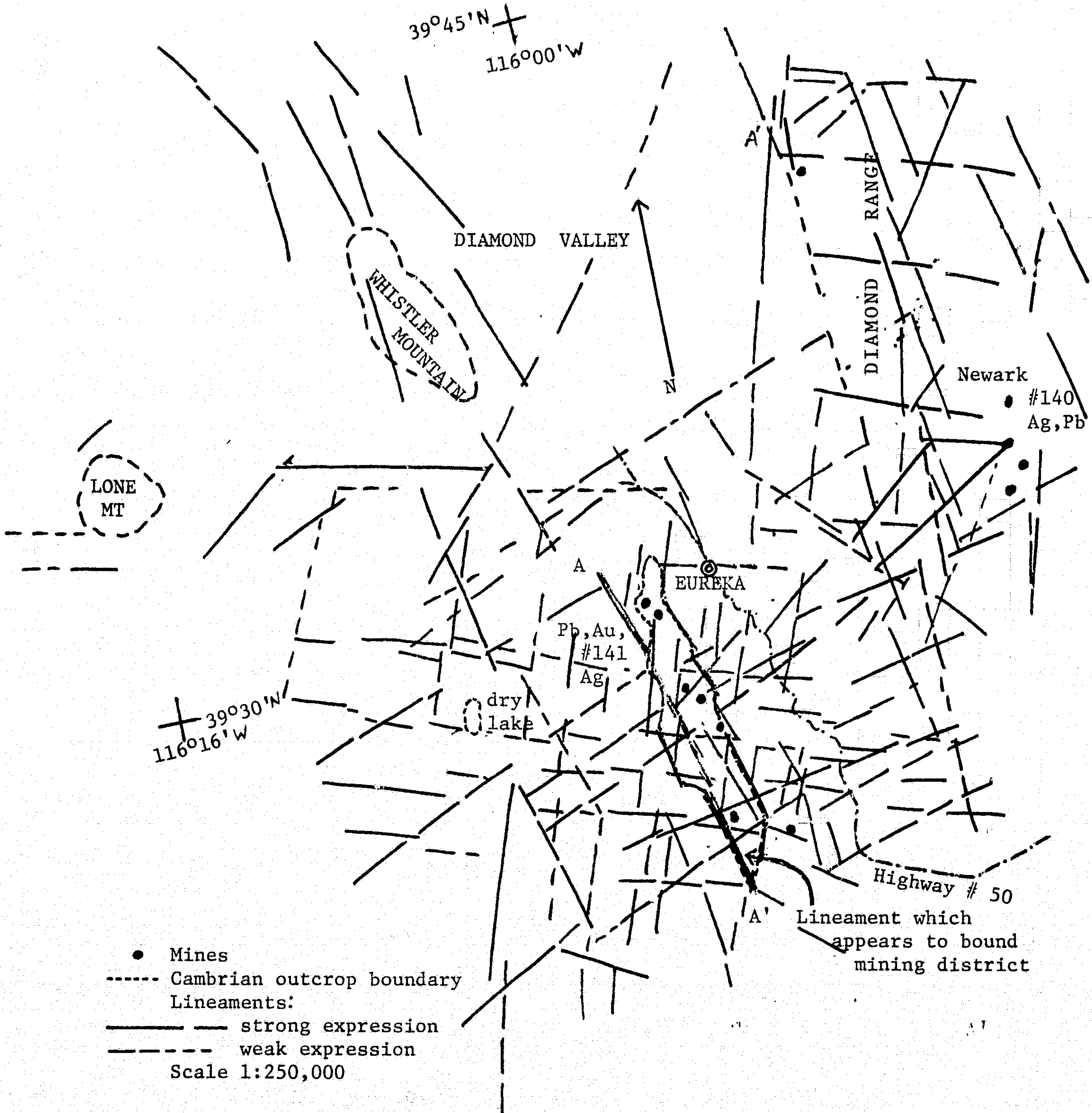


Figure 11: EUREKA MINING DISTRICT: LANDSAT LINEAMENTS
Eureka County, Nevada

Lineaments from LANDSAT Frame E-1755-17450

Nevada).

A northwesterly alignment of lineaments parallels the long axis of the Cambrian outcrop area, but the linear segments are broken and offset across the mining district. An 8 to 10 km wide zone of northeasterly trending lineaments, normal to the northwesterly alignment, appears to be terminated at the Cambrian outcrop area.

An 8 to 10 km wide zone of north-south lineaments also passes through the district, with the set broken into short and somewhat disoriented segments through the district. A similar zone of east-west lineaments can be traced through the district, also short and somewhat disoriented.

No single continuous lineament can be traced through the Eureka mining district which appears to be related to the mineralization.

Similar relationships are found on the U-2 imagery of the Eureka mining district (figure 12), except that the lineaments show more scatter, less continuity of alignment. Several orientations were mapped which were not evident on the Landsat (N 30^{o} E, N 60^{o} W), and the east-west set was not mapped as a prominent set.

c. Central Wasatch Mountains

On the Landsat imagery, an east-west lineament can be traced for 30 km as an alignment of linear features across the Wasatch Mountains from the Wasatch Fault on the west to the western tip of the Unita Mountains on the east (Figure 13). The linear features are from 0.5 to 5 km long and slightly offset after alignment offset.

Two northeasterly trending lineaments can be traced, one northwest of the mining districts, the other to the southeast. The mines (locations taken from the Salt Lake AMS sheet, NK 12-11) fit between these lineaments, forming a block about 10 x 15 km. The northeasterly lineaments appear to be terminated to the southwest within the Wasatch Mountains and to the northeast against the Tertiary volcanics in Heber Valley. Within the block, other northeasterly lineaments are traceable as short and scattered linear features.

On the U-2 imagery (figure 14), a N 80^{o} E lineament can be traced as an alignment of broken and slightly offset linear segments along Little Cottonwood Canyon, on the east, across the Alta and Brighton mining districts to Park City, where it appears to be terminated.

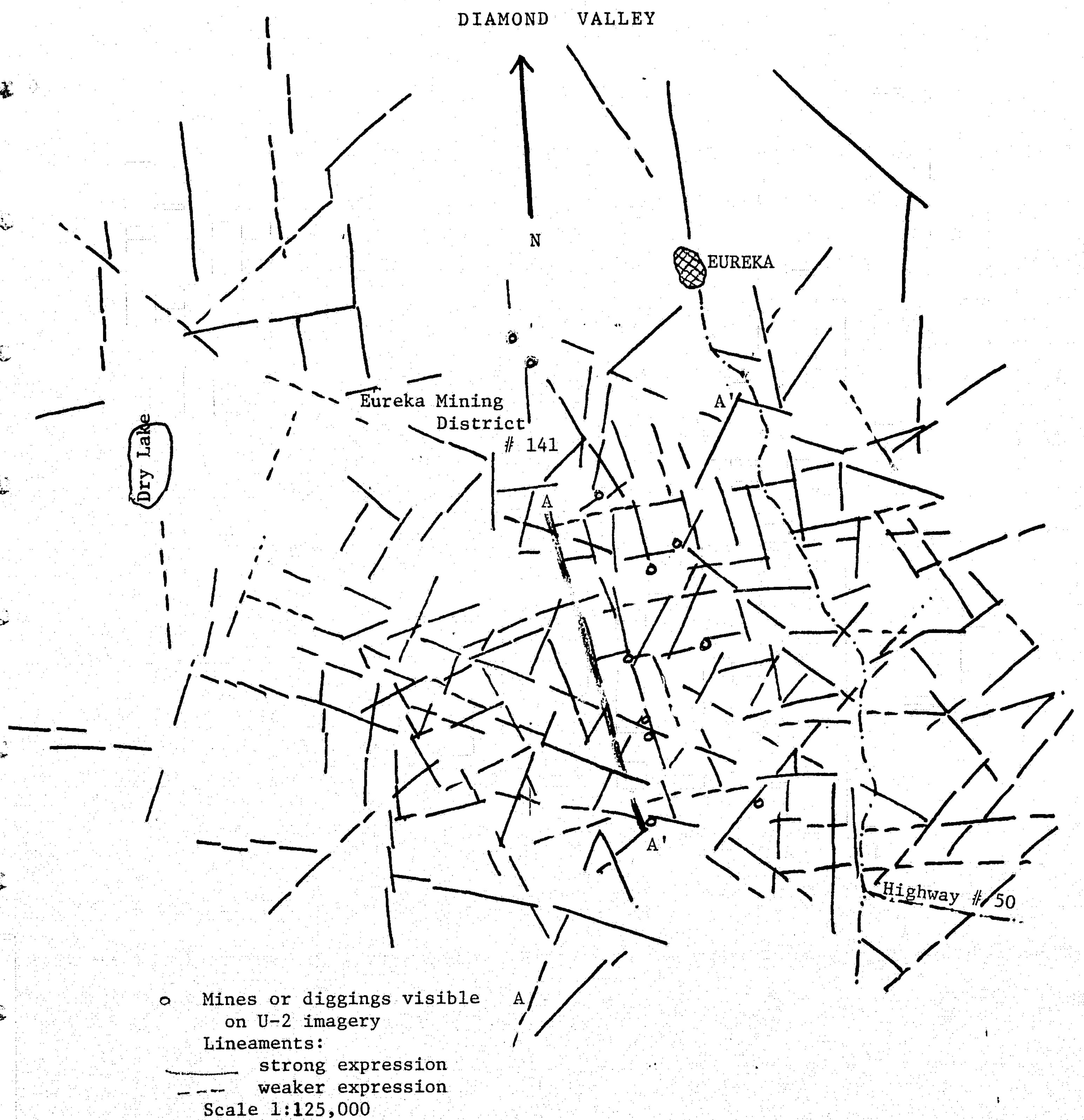
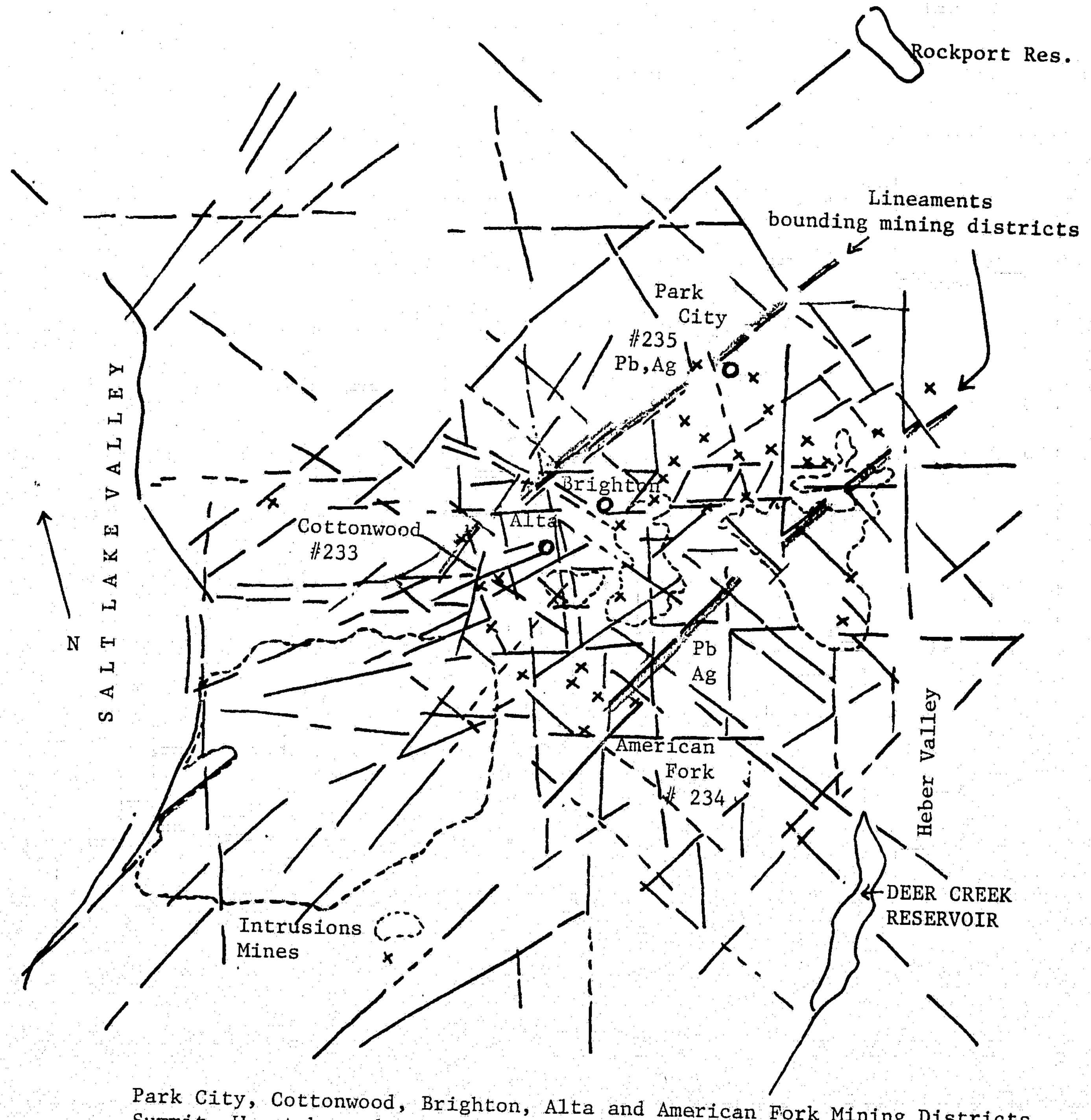


Figure 12: EUREKA MINING DISTRICT: U-2 LINEAMENTS
Eureka County, Nevada



Park City, Cottonwood, Brighton, Alta and American Fork Mining Districts
Summit, Wasatch, and Utah Counties, Utah
Lineaments from LANDSAT Frames E- 1392-17361-5 and E-1771-17323-5
Scale 1:250,000 Geology from Geologic Map of Utah

Figure 13: CENTRAL WASATCH MOUNTAINS: LANDSAT LINEAMENTS

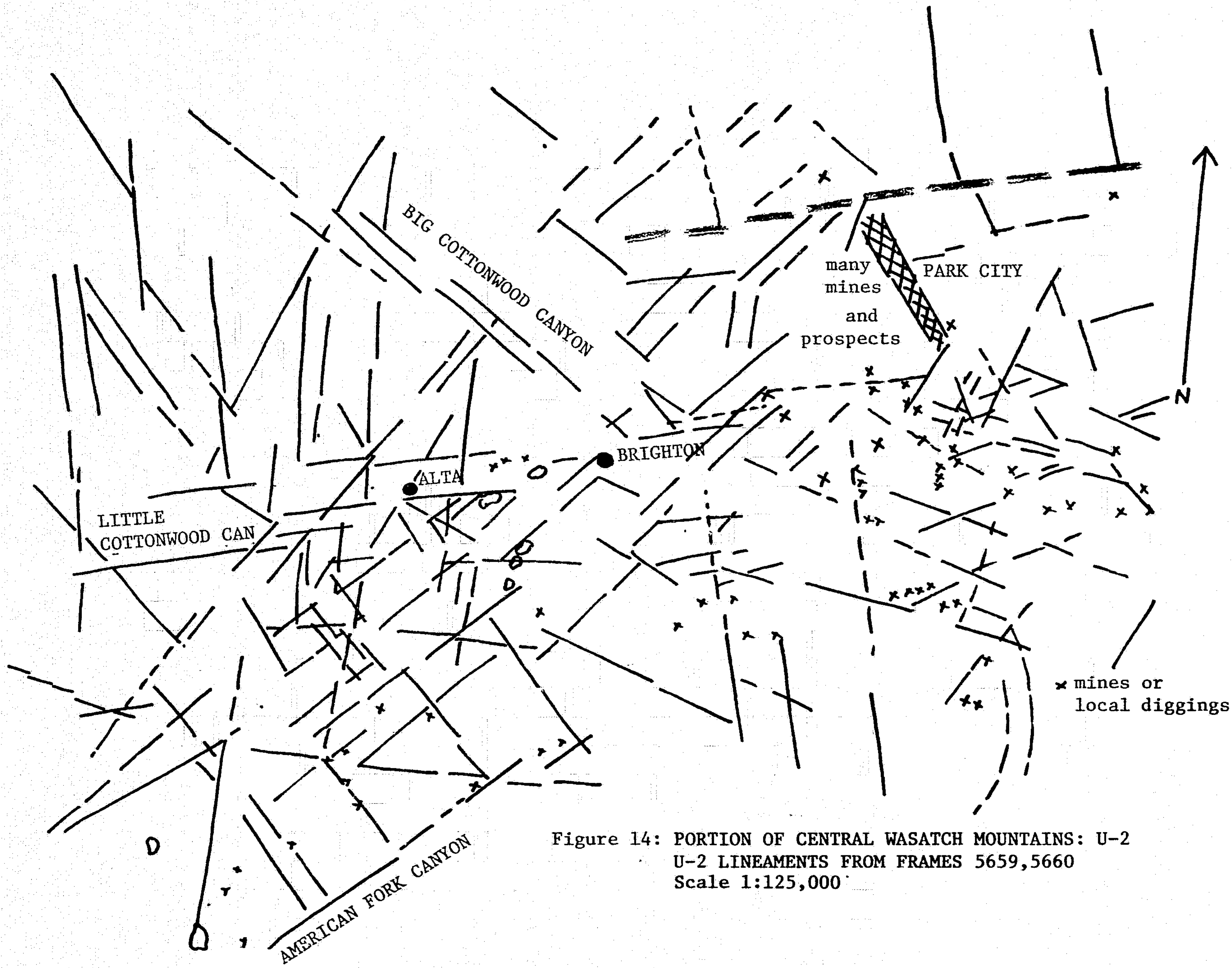


Figure 14: PORTION OF CENTRAL WASATCH MOUNTAINS: U-2
U-2 LINEAMENTS FROM FRAMES 5659,5660
Scale 1:125,000

The east-west set described above for the Landsat imagery was not mapped from the U-2 imagery except to the east of SE of Park City, where it appears as a set of very short and broken linear features.

A zone of northeasterly linear features was traced across the district as short and scattered lineaments, but not as a continuous alignment.

The mineralization in these mining districts occurs primarily within northeasterly trending faults and fissures. This would suggest that the short lineaments or lineament segments may be directly related to the mineralization, but not the longer, more continuous lineaments which appear to bound the district rather than cross it.

d. Oquirrh Mountains

No single lineament can be traced across these mountains. North, east, northeast and northwest trending lineaments are mapped as relatively short and disconnected segments, up to 5 km in length, within the mountains (figures 15 and 16). The northwesterly alignment of the Stockton, Ophir and Mercur mining districts parallels a set of northwesterly lineaments and range front faults, but no single lineament or lineament alignment is mappable through the districts.

The U-2 1:125,000 scale tracing of the central part of the Qquirrh Mountains (figure 16) again shows no through-going lineaments. No lineaments can be traced across the Bingham pit, from which more than 75 million dollars value in copper, silver, and gold ore has been mined.

e. Tintic Mountains

No lineaments can be traced across the Tintic Mountains as single alignments of topographic linear features (figures 17 and 18)

Two north trending alignments follow range front boundaries; a third alignment parallel to and between the first two can be mapped through the central part of the Tintic Mountains. All three show apparent offsetting along a N 80^{o} W lineament alignment that follows the south boundary of the West Tintic Hills, and bisects the Tintic Mining District.

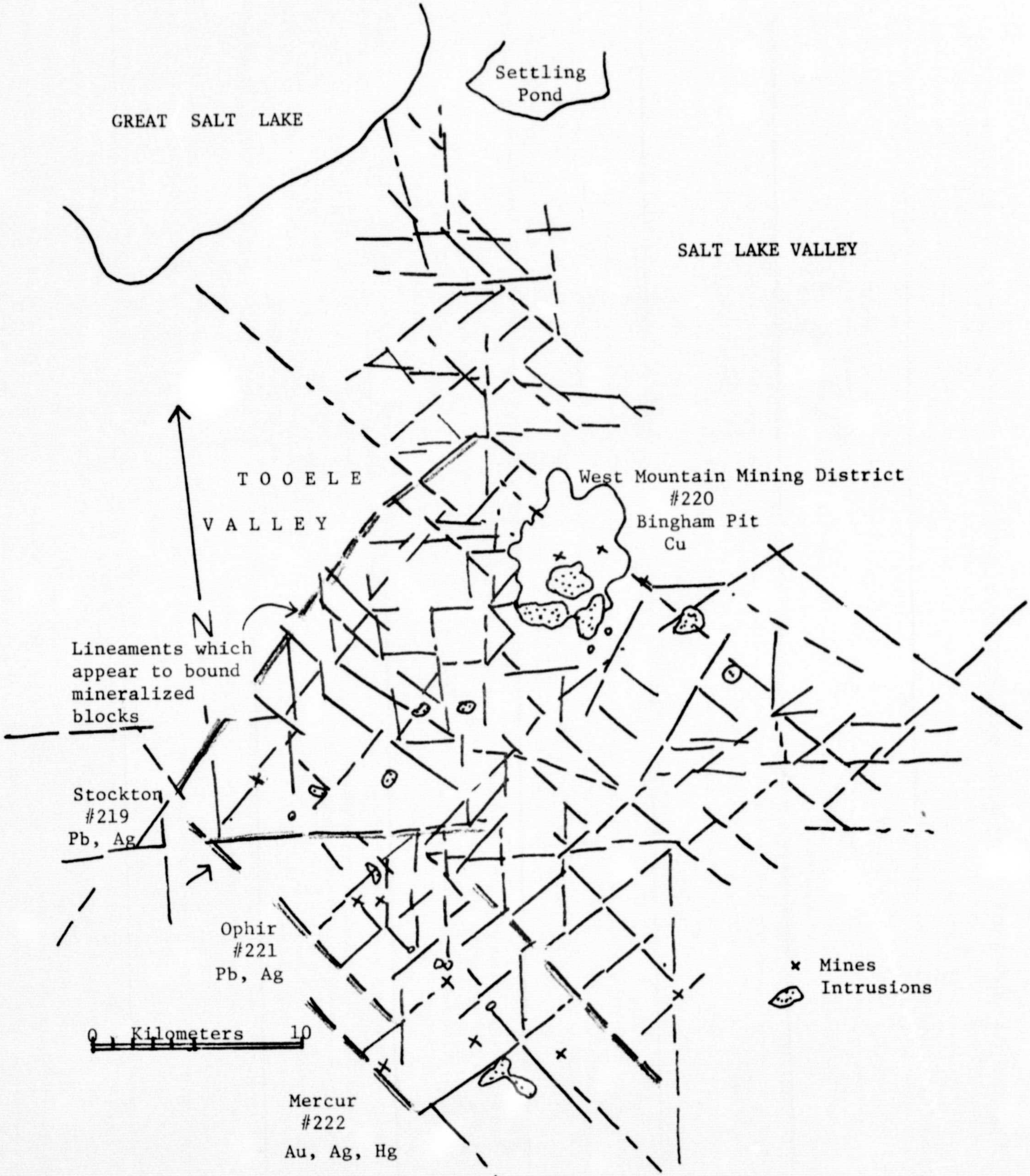


Figure 15: OQUIRRH MOUNTAINS: LANDSAT LINEAMENTS
Tooele and Salt Lake Counties, Utah
Lineaments from LANDSAT E-1771-17323-5

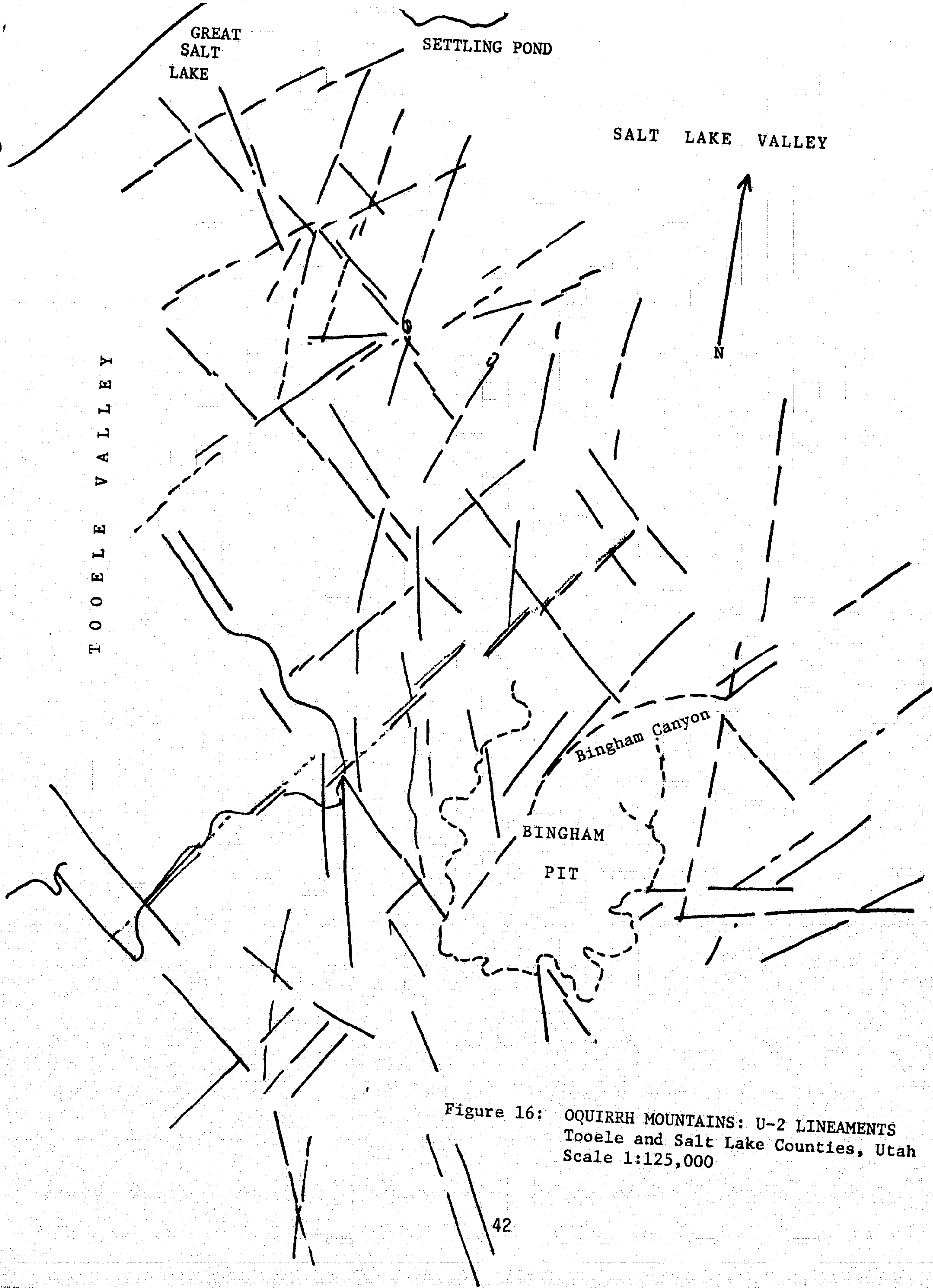


Figure 16: OQUIRRH MOUNTAINS: U-2 LINEAMENTS
Tooele and Salt Lake Counties, Utah
Scale 1:125,000

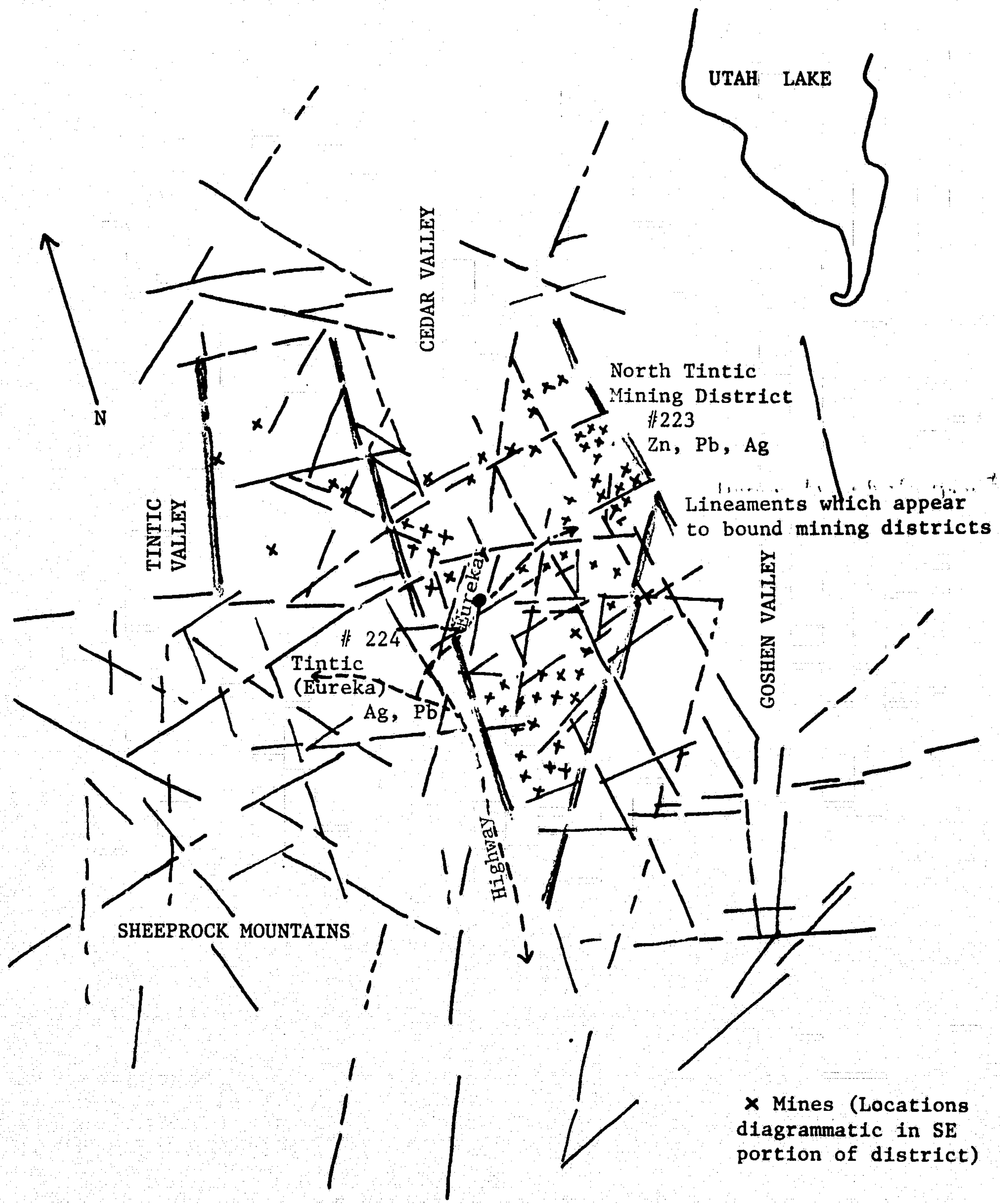


Figure 17: TINTIC MOUNTAINS: LANDSAT LINEAMENTS
Utah and Juab Counties, Utah
Lineaments from LANDSAT E-1771-17323-5
Scale 1:250,000

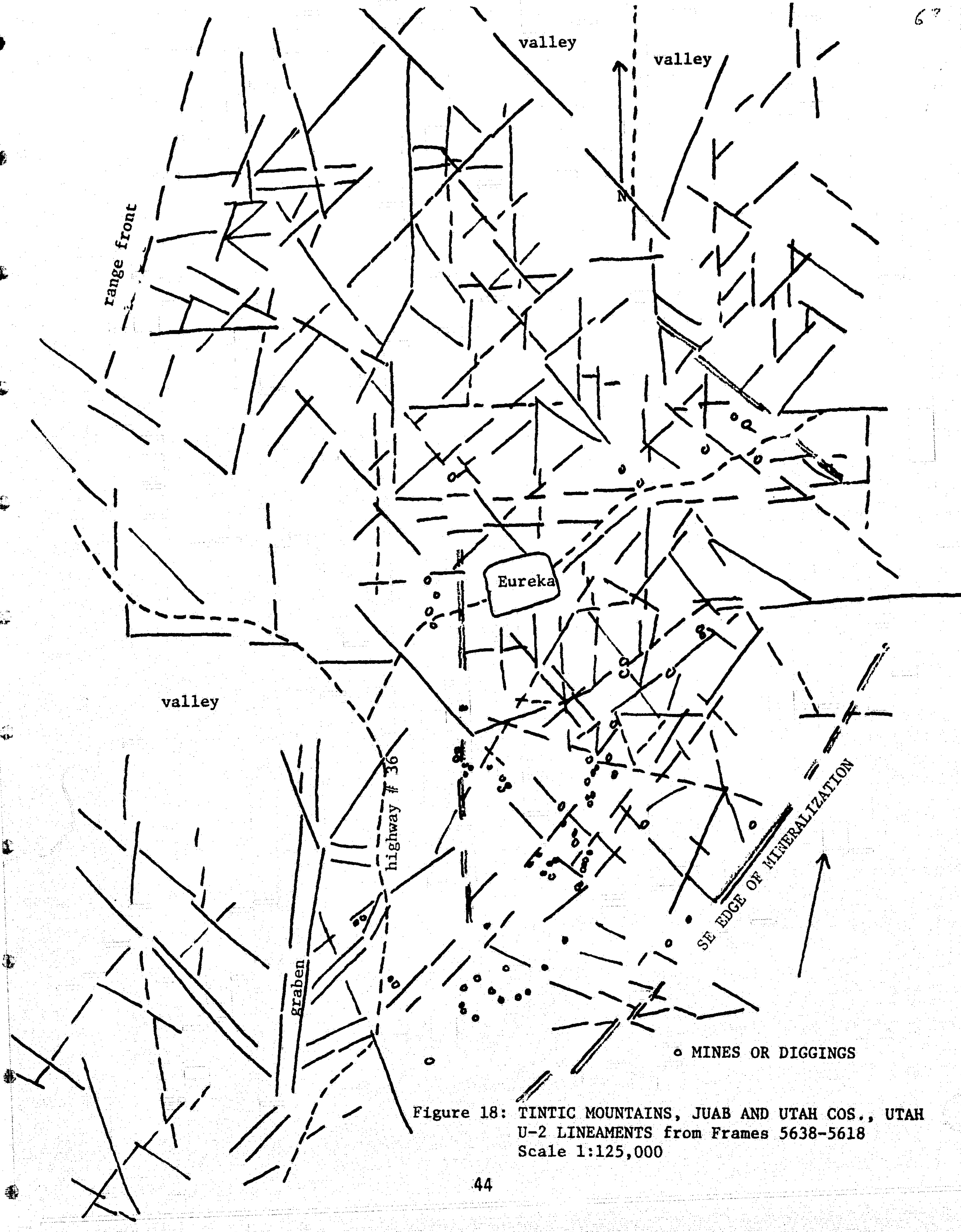


Figure 18: TINTIC MOUNTAINS, JUAB AND UTAH COS., UTAH
U-2 LINEAMENTS from Frames 5638-5618
Scale 1:125,000

A set of discontinuous northeasterly lineaments crosses the entire Tintic Mountains. One of these appears to be the southeast boundary of the mineralized outcrop area. Most of the mines in the Tintic and Eureka districts fall within a block bounded by the N 30° E and north trending lineaments, the sides of which are about 14 and 6 km long, respectively. The veins in the district have north and northeast azimuths; it is possible that both veins and northeasterly lineaments are related and are the result of the same stress system.

The same relationships are seen on the U-2 imagery.

In none of the four regions, which include 12 mining districts, is there a lineament which can be traced across a mining district and which appears to be related to the mineralization. Those which do cross districts (as the east-west lineament across the central Wasatch Mountains) are apparently not related to the mineralization, and are not mappable as a single line but rather as alignments of short and slightly offset linear features.

Lineaments within the mining districts appear as relatively short (less than 5 km in length) and scattered or broken segments, as mapped from both Landsat and U-2 imagery, and all terminate within the district. Lineaments greater than 5 km bound rather than cross mining districts.

C. Correlation of Lineaments with Geology

1. Correlation of Lineament Intersections

To find what geologic correlation, if any, there is with the intersections of lineaments, forty lineament intersections located on the Reno AMS sheet lineament overlay (figure 23) from the random azimuth lineament selection (section D-1-a and Plate 4) were numbered and compared with the 1:250,000 scale county geologic maps of Churchill, Douglas, Ormsby, Storey, and Lyon Counties in Western Nevada. The location of the intersections (within range, on range boundary, or in basin) was noted; the rock type found at the intersections, and the presence of any mapped faults (Table 3). Only two of these intersections have mines within 1 km.

TABLE 3

Lineament intersections from RENO AMS Sheet lineament overlay
(Intersections are numbered on overlay)
Compared with geologic maps of Lyon, Washoe, Storey, Ormsby,
Douglas, & Churchill Counties, Nevada (1:250,000)

Location: RBY = range boundary
B = basin
I = interior
Rock Type: Int = intrusive V = volcanic S = sediments
Ba = basalt A = andesite R = rhyolite

On mapped fault = F

INTER-# SECTIONS	LOCATION	ROCK TYPE	MAPPED FAULT PRESENT	INTER-# SECTIONS	LOCATION	ROCK TYPE	MAPPED FAULT PRESENT
1	RBY	Ba	F	22	B		
2	I	R		23	I	Ba,A	F
3	I	Ba		24	RBY	A	
4	B	Ter		25	RBY	A	F
5	I	Ba		26	RBY	A	
6	RBY	A		27	RBY	A,S	
7	I	A		28	RBY	Int	
8	I	A		29	RBY	Int	
9	I	B,A		30	OFF MAP		
10	RBY	Ba,S		31	RBY	Int	
11	I	lake beds		32	RBY	Int	
12	I	Int		33	RBY	Int	
13	I	Int		34	I	V	
14	I	Int		35	OFF MAP		
15	RBY	Int		36	I	V	
16	I	R		37	RBY	V	
17	RBY	Ba,R	F	38	RBY	Int	
18	RBY	Ba,R	F	39	I	V	
19	B	Ba		40	I	V	F
20	B	Ba		41	IB	S	
21	B	Ba					

17 of 39 intersections are along range boundaries
10 of " " " in intrusives
6 of " " " on mapped faults
2 (no. 17 18) intersections in mining districts

TABLE 3: Correlation of lineament intersections with geologic maps

Seventeen of the forty intersections fall along range fronts; ten are on intrusives, and only six are on mapped faults.

Conclusion: Intersections of lineaments selected in the initial lineament study do not appear to have any consistent relationship to geology, as mapped on the 1:250,000 scale.

2. Effect of Scale

To find what effect scale has on the location or selection of a lineament, three tracings were made of a prominant lineament which can be traced along and across the range on the east side of Diamond Valley in central Nevada (Eureka County), from Landsat imagery at three scales. These are:

1) 1:1,000,000 Landsat Mosaic of Nevada,
2) 1:500,000 Landsat E-1071-17540 and 17533, Band 7.
3) 1:250,000 Landsat E-1774-17493, Band 5

The tracings (figures 19, 20, and 21) show that a lineament which appears as a simple straight line on the 1:1,000,000 scale print appears as an alignment of short lineaments or lineament segments at the larger scales, with some segments showing slight skewing of azimuth. Alignments may not be as apparent on the larger scale; that is, the shorter segments may not be identified as portions of a single lineament.

Lineaments which are visible as a tonal boundary (across a basin area) may be completely lost on another band, possibly because they are boundaries of areas of vegetation.

3. Field Check of Lineament

A lineament traced for 50 km across the Central Nevada Mountains (A-A' on figure 22-A and 22-B) was field checked at several places along its length to look for evidence of fracturing and continuity.

The lineament was traced as an alignment of linear topographic features from 1:250,000 scale prints of Landsat E-1771-17323 - 5 and E-1753-17331 - 5. It extends N 45^{o} W from the northeast end of Deer Creek Reservoir on the southeast, to the Wasatch Front north of Salt Lake City on the northwest. The lineament is approximately 75 percent topographic and has been seen by at least six operators.

Other lineaments parallel to this trend have also been traced on

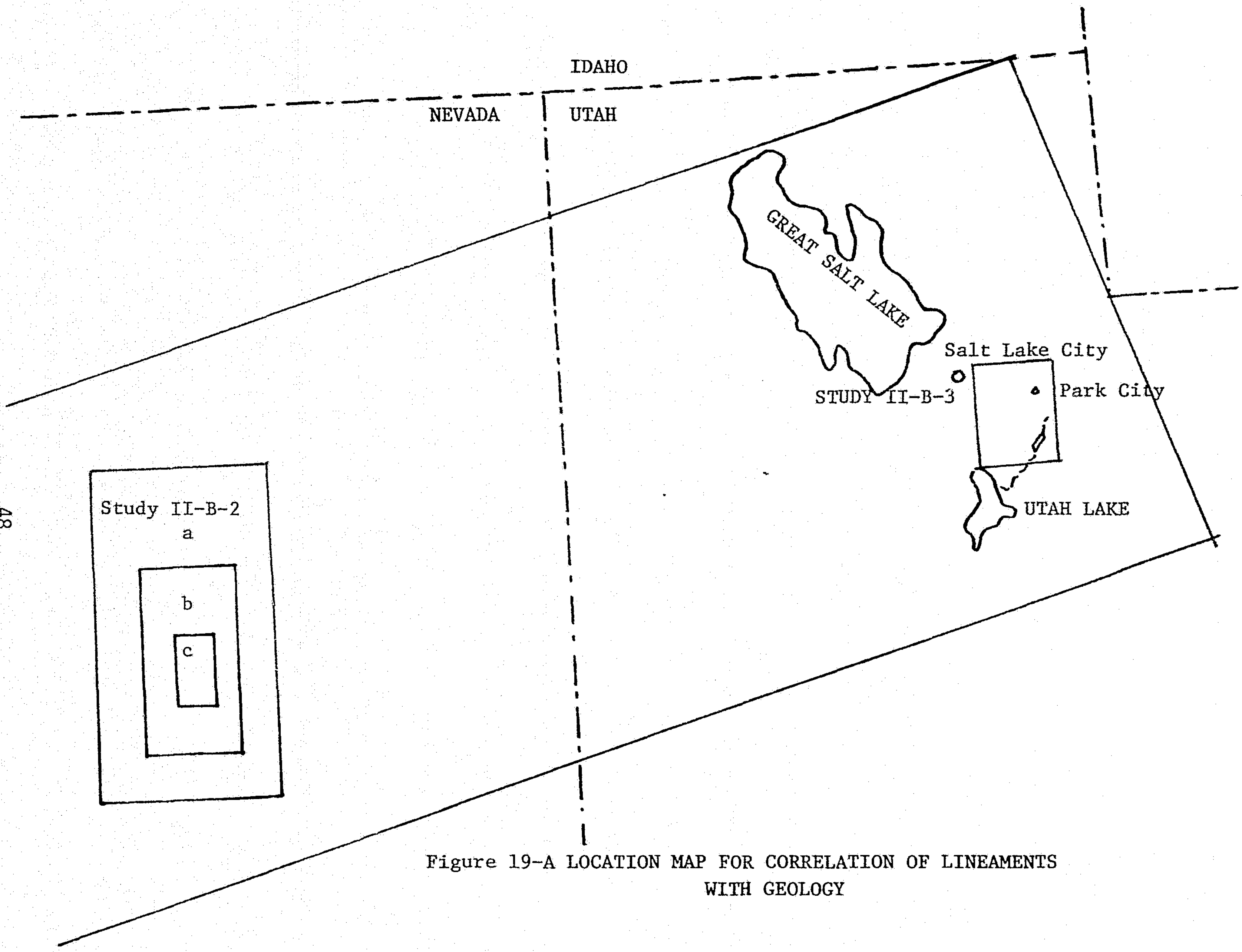


Figure 19-A LOCATION MAP FOR CORRELATION OF LINEAMENTS WITH GEOLOGY

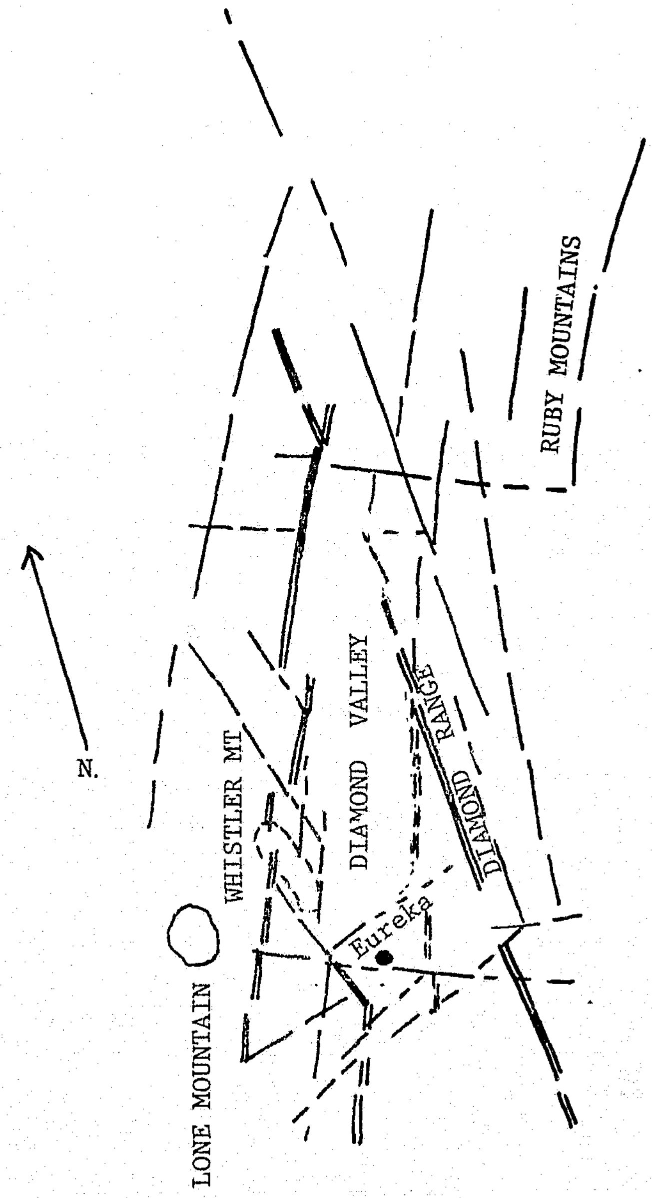


Figure 19: EFFECT OF SCALE ON THE APPEARANCE OF LINEAMENTS
DIAMOND VALLEY AND DIAMOND RANGE, EUREKA CO., NEV.
From LANDSAT Imagery, 1:1,000,000 scale

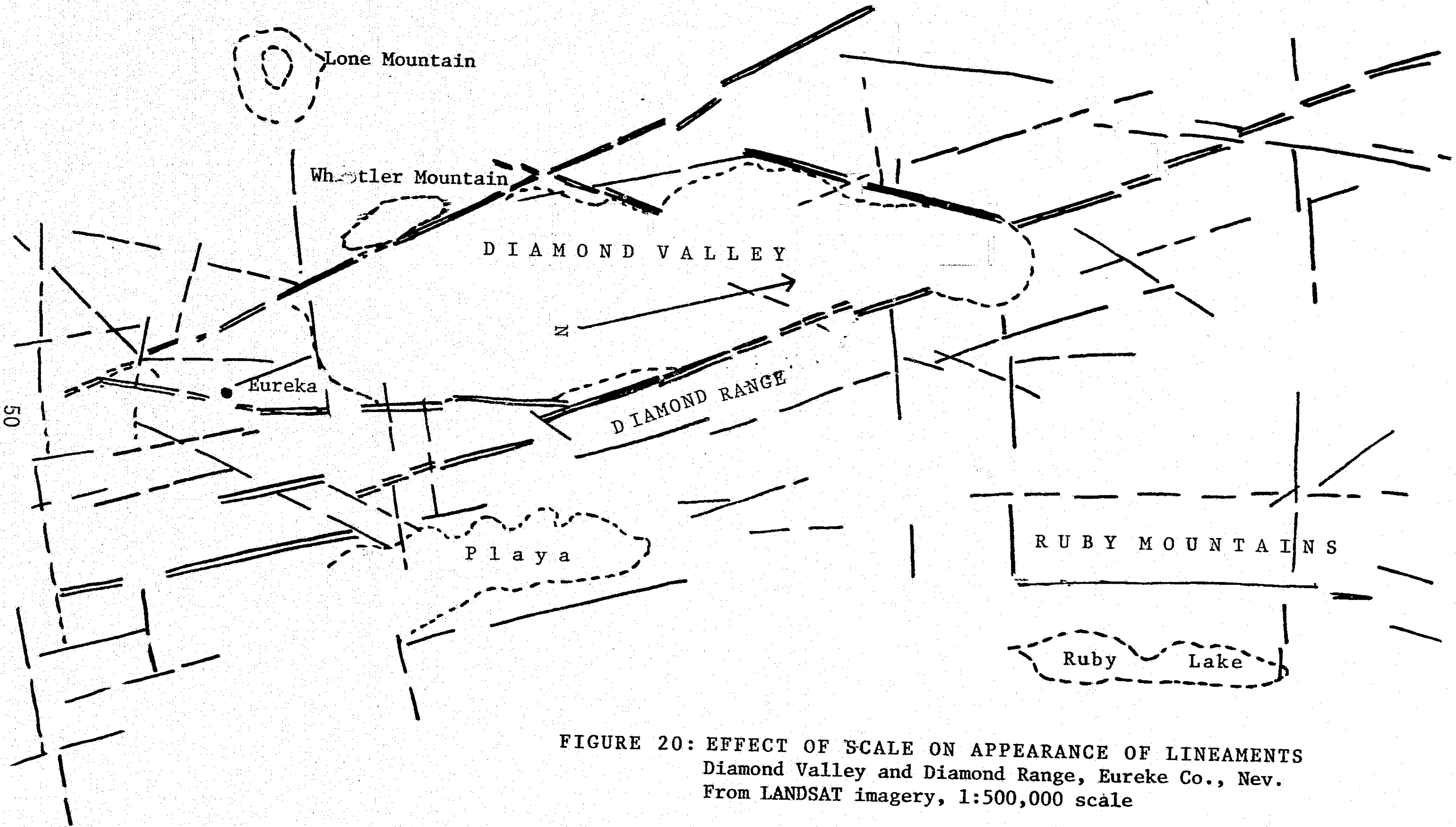


FIGURE 20: EFFECT OF SCALE ON APPEARANCE OF LINEAMENTS
Diamond Valley and Diamond Range, Eureke Co., Nev.
From LANDSAT imagery, 1:500,000 scale

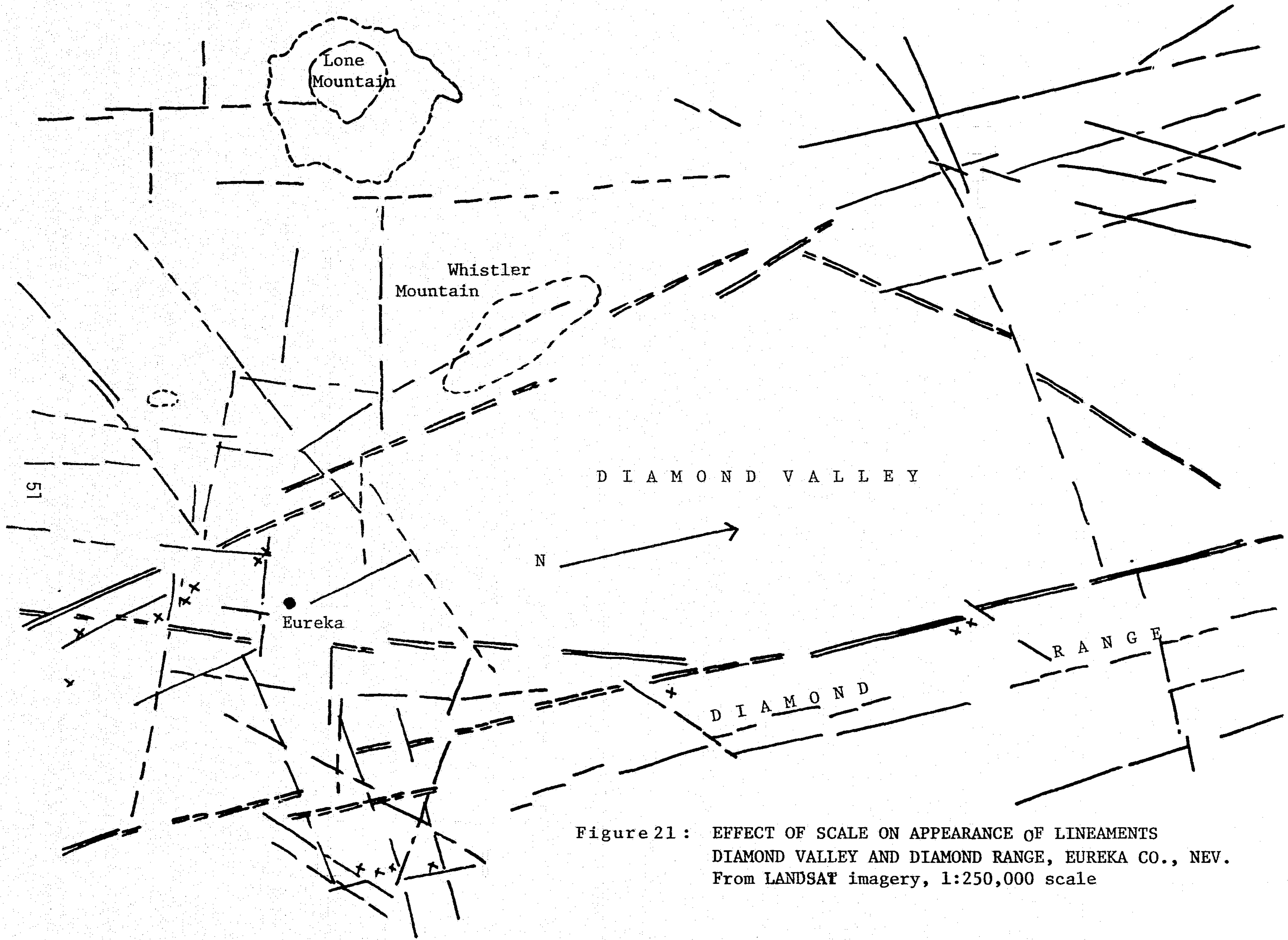


Figure 21: EFFECT OF SCALE ON APPEARANCE OF LINEAMENTS DIAMOND VALLEY AND DIAMOND RANGE, EUREKA CO., NEV. From LANDSAT imagery, 1:250,000 scale

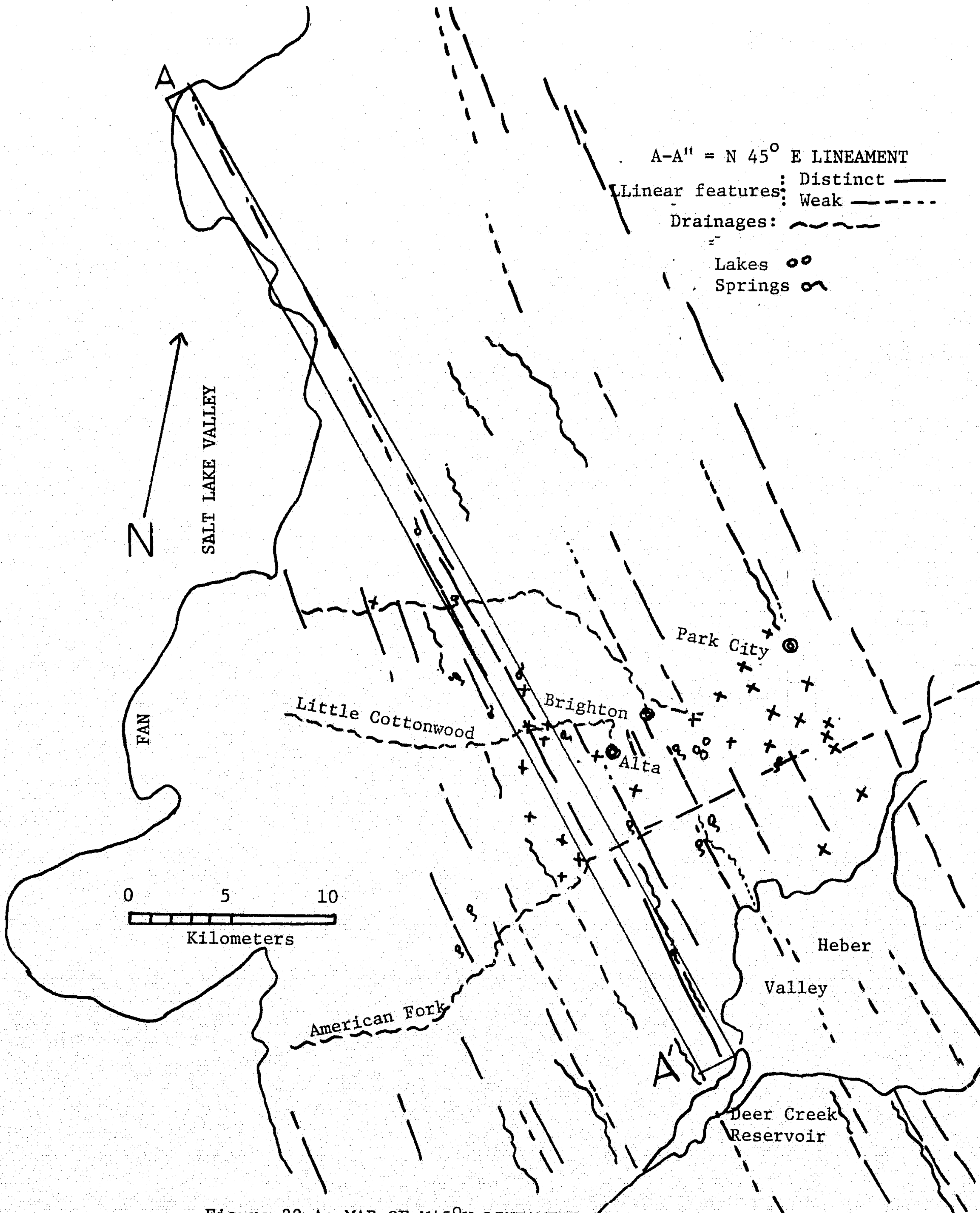


Figure 22-A: MAP OF N45°W LINEAMENT ACROSS CENTRAL WASATCH MOUNTAINS WITH DRAINAGES AND OTHER PARALLEL LINEAR FEATURES From Landsat E-1771-17323

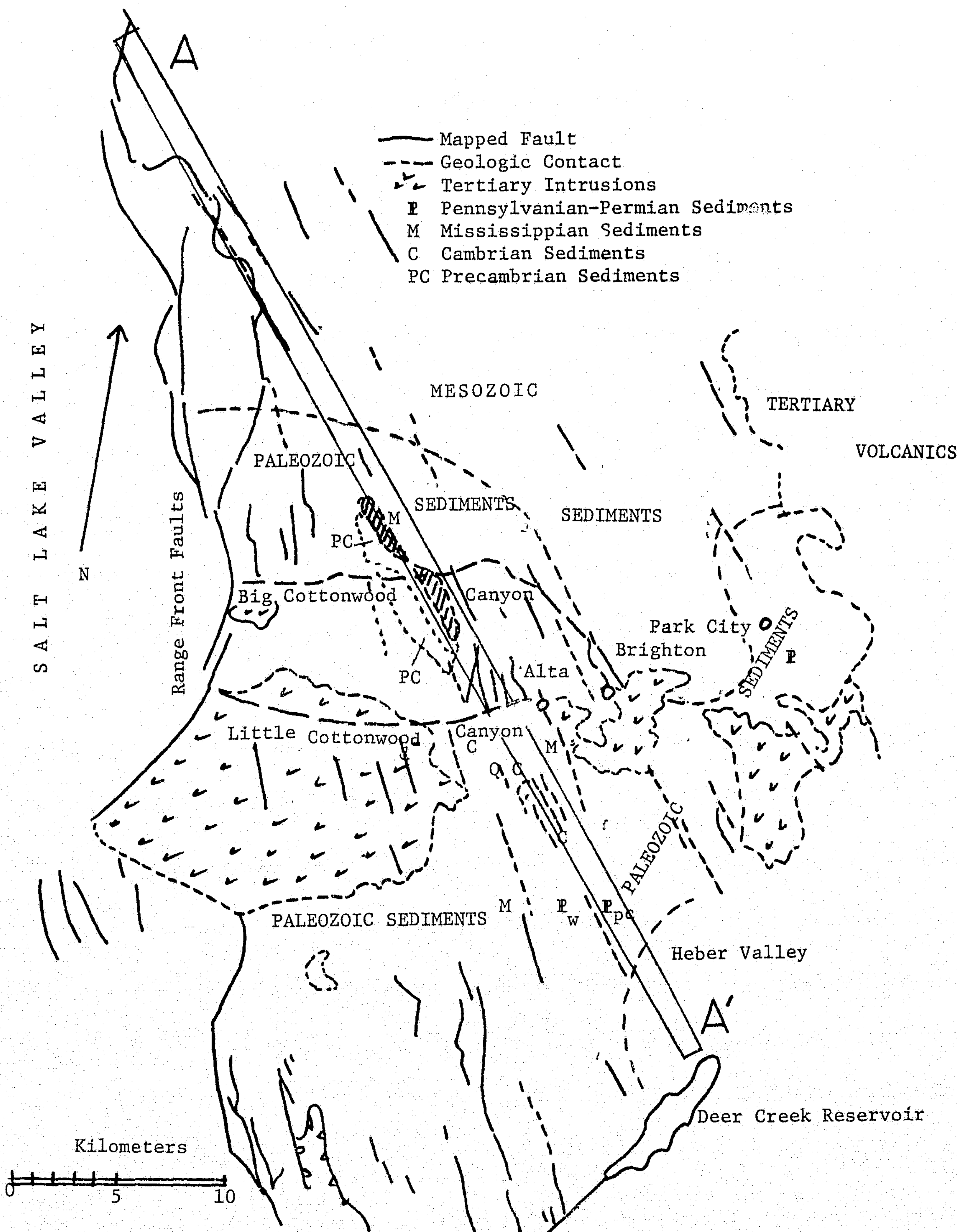


Figure 22-B FAULTS AND GEOLOGIC CONTACTS ACROSS CENTRAL WASATCH MTS PARALLEL TO N45°W LINEAMENT A-A'
(From Geologic Map of Utah, 1965)

Figure 22-A, and drainages, springs, lakes, and mines have been mapped from the Salt Lake AMS sheet (NK 12-11). Figure 22-B is a tracing of the faults and geologic boundaries parallel to the lineament, from the Geologic Map of Utah (Stokes, 1963), with the lineament drawn on it for reference.

The lineament follows several geologic contacts (Precambrian-Cambrian and Cambrian-Mississippian) in its central part, north and south of Little Cottonwood Canyon, for a total distance of about 10 km, and several mapped faults also for a total distance of 10 km. Northwest of Deer Creek Reservoir it follows a steep drainage up into rounded, soil-covered terrain. At the top of the slope a new road-cut exposed an unmapped northwesterly trending fault zone 15 feet wide with quartz vein filling. This fault could be traced for a little over a hundred feet. To the northeast of the fault, the lineament follows topographic hollows or ridges, along a Quaternary gravel-filled basin. Northwest of American Fork Canyon the lineament follows a Cambrian-Mississippian contact for approximately three km. Northwest of Little Cottonwood Canyon it also follows Cambrian-Mississippian and Cambrian-Precambrian contacts. Several springs were noted along the lineament, including one where the lineament crosses Big Cottonwood Canyon.

This lineament (or fractures of this orientation) has no reported relationship to the mineralization in the Cottonwood and American Fork mining districts, through which it passes. However, there is a cluster of three mines where it crosses Little Cottonwood Canyon.

The width is variable and uncertain. It may follow a single topographic linear feature, or a zone of smaller parallel or near-parallel features as much a 1 km in width. As seen on the map (figure 22-A), it may be part of a wide (35 km) zone of parallel or near-parallel linear features. The eastern edge of this zone follows approximately the western edge of the Tertiary volcanics in Heber Valley, east of the Central Wasatch Mountains (figure 22-B). Its southwestern edge parallels the Wasatch Front northeast of the Utah Lake basin.

The lineament can be followed as a single alignment or narrow zone of relatively short (0.5 to 2 km) linear features for four to five km at its northwestern and southeastern termini; between American Fork Canyon and Big Cottonwood Canyon the linear features show more scattering and

disorientation especially as traced from a 1:62,000 scale Forest Service photomosaic of the Central Wasatch Mountains. This may be, in part at least, the effect of the rugged topography, but in several places there is evidence that the termination or offsetting of various linear features appears to be dislocation along transecting faults or other crosscutting linear structural features.

It is concluded that the lineament cannot be traced on the ground as a single continuous linear feature. It is an alignment or zone of relatively short and discontinuous topographically expressed linear features, in places well aligned and closely spaced, in others scattered and disoriented; mapped geologic boundaries and faults lie along approximately two-fifths of its length.

D. Relationships of Lineaments and Intrusions

1. Lineaments and Intrusions

Several lineament studies were made in an attempt to find a method for locating intrusions on Landsat imagery using lineaments mapped from Landsat imagery. The following three studies tested the possiblity that,

a) intrusions might locally mask the expression of lineaments,

b) lineaments of one azimuth might show preferential expression across intrusions, and

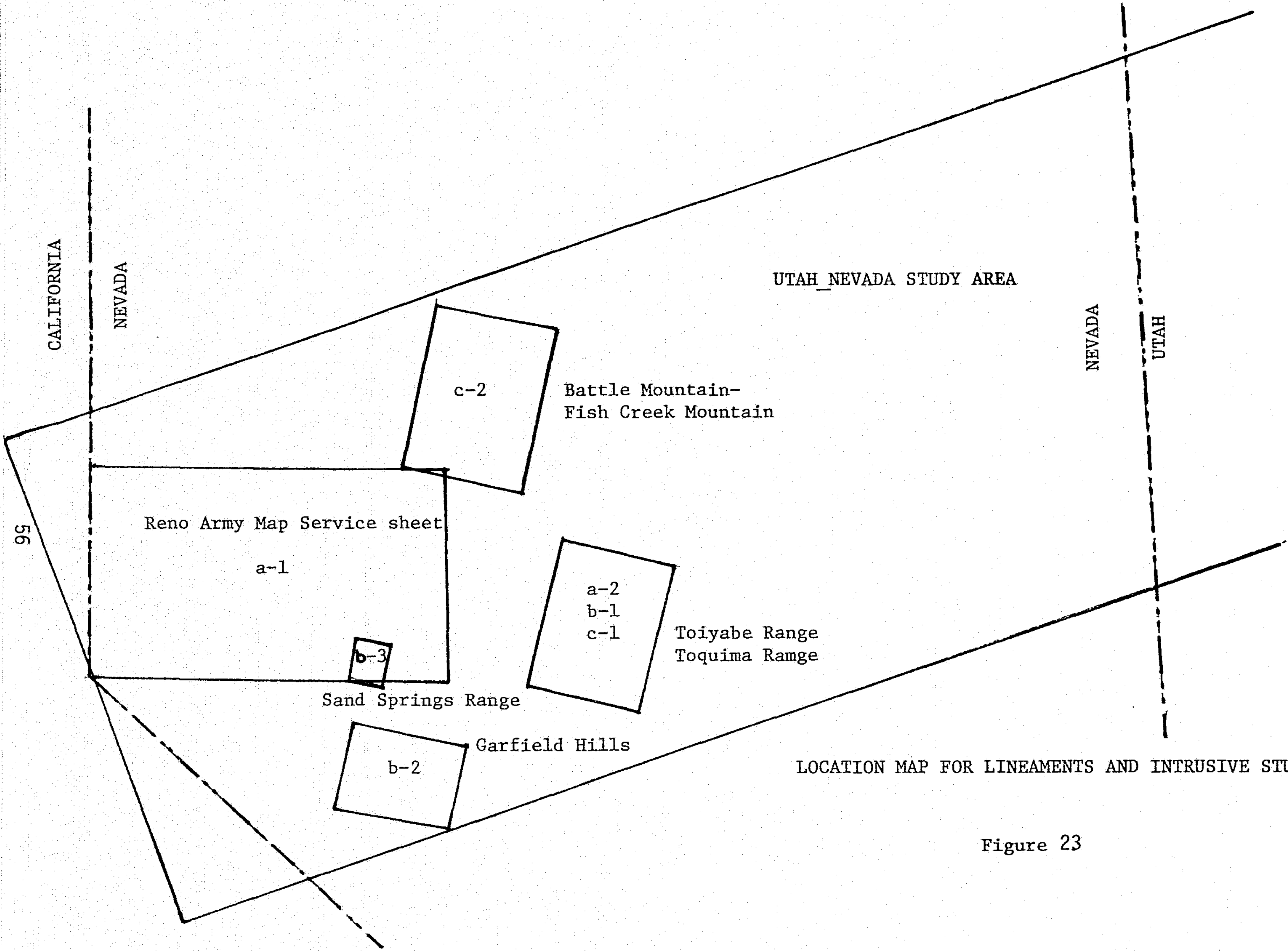
c) arcuate or concentric lineaments might reflect doming caused by intrusions.

Figure 23 shows the locations of these studies.

a. Areas free of lineament intersections

To find if areas free of lineament intersections (as mapped from Landsat imagery) may be indicators of the presence of intrusions, assuming that intrusive rocks may obliterate the pre-existing fracture systems, a preliminary study was made using two sets of lineaments traced from 1:250,000 scale prints of Landsat E-1937-18051-3. The area covered by this imagery is shown at A-1 on Figure 23. The lineaments had azimuths of N $\pm$ 10^{0} and E $\pm$ 10^{0}. Criteria for their selection is given in study D-2-a,b,c.

It was noted in study D-2 that there were areas free of lineament intersections within the ranges, when the tracings of the two sets



LOCATION MAP FOR LINEAMENTS AND INTRUSIVE STUDIES

Figure 23

of lineaments were compared with the geologic map of the area (Geologic Map of Mineral Country, Nevada, 1974). Seventeen such areas were delineated, roughly circular to elongate in plan, and 5 to 20 km in diameter. Seven of the areas contained intrusions, 9 contained mining districts.

Since this area has a very large number of intrusions and mining districts, a second test was made on a 1:500,000 scale print of Landsat E-1396-17592-5, of the Paradise, Toiyabe, and Toquima Ranges in Nye County, Nevada (A-2 on figure 23). Eight separate tracings were made for lineaments having limited azimuthal ranges of N 80-55° W; N 55-35° W; N 35-10° W; N 10° W-10° E; N 10-35° E; N 35-55° E; N 55-80° E; and N 80-100° E. These tracings were superimposed to locate areas free of lineament intersections (after all basin areas were eliminated).

Thirty-two such areas were located, ranging from 5 to 10 km in diameter. Figure 24 shows three of the eight sets of lineaments and the lineament-free areas present when all eight sets are superimposed. These areas were compared with the 1:500,000 scale Preliminary Geologic Map of Nevada. Of the 32 areas, 7 contain intrusives; 4 contain mining districts, and 2 contain both.

It is concluded that local absence of traceable lineaments or areas lacking lineament intersections do not appear to be promising exploration tools for the location of intrusions.

b. Northeast and northwest trending lineaments

To find if intrusions can be located by the presence or absence of a particular set of lineaments, six of the lineament sets traced across the Toiyabe and Toquima Ranges in study II-D-1-a were superimposed on geologic maps to locate areas of intrusive outcrop. A count was made of the northeasterly and northwesterly trending lineaments across, partly across, and bounding each intrusion (Table 4). Counts were also made of lineaments of the same azimuths traced from U-2 and low altitude photography of the Garfield Hills and Sand Springs Range (see location map, figure 23).

Chi-square tests were made of the lineament counts to determine any preferred orientation of lineaments across the intrusives. In every test, at levels of significance of 0.05 and 0.1, the calculated

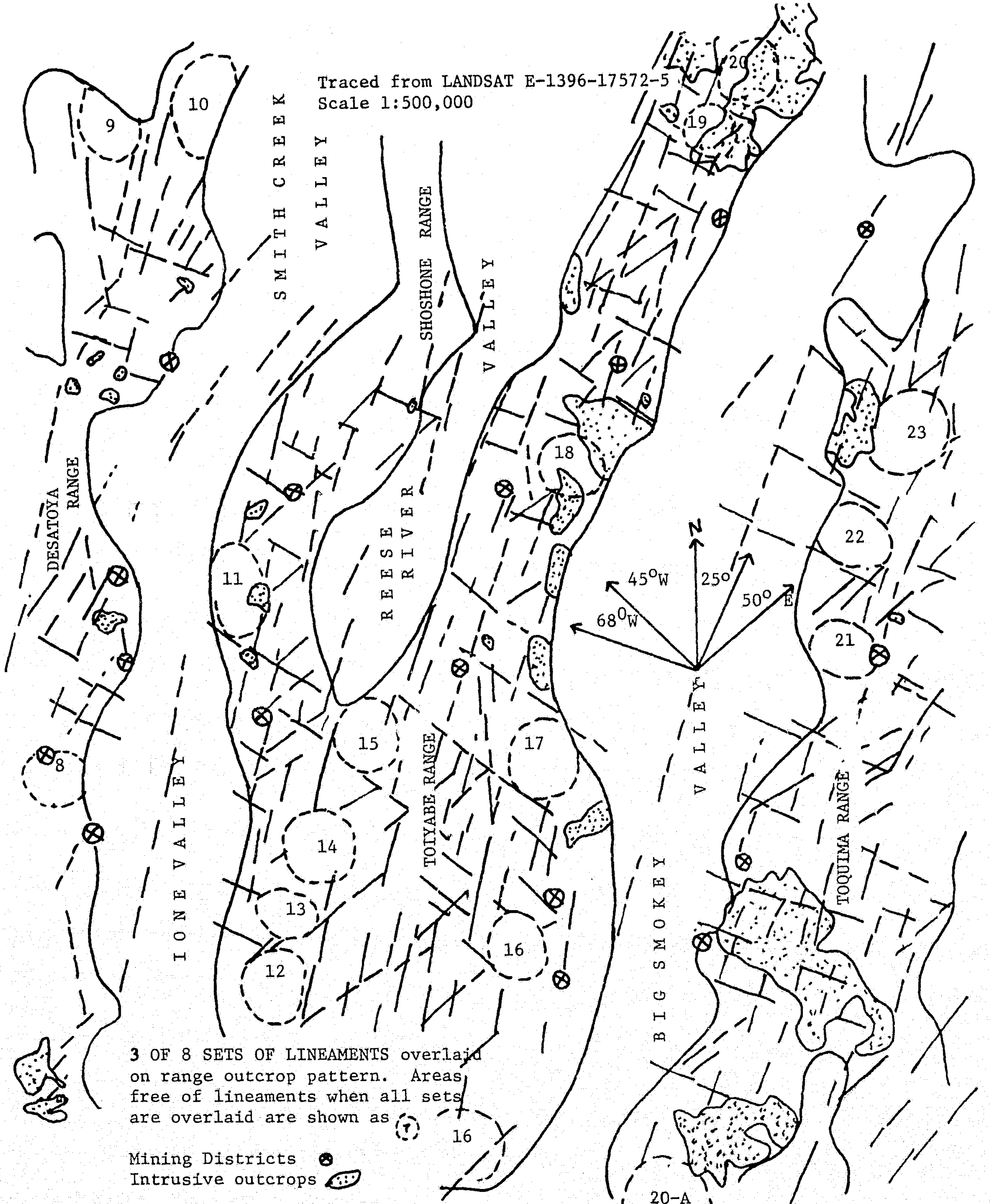


Figure 24: AREAS FREE OF LINEAMENT INTERSECTIONS TOIYABE AND TOQUIMA RANGES, NYE CO., NEVADA

GARFIELD HILLS

Imagery-Landsat E 1397-18051-5 scale 1:250,000

Overlay tracing of lineaments crossing or bounding intrusives

Lineaments	E		N E		CENTRAL		S W		SE		Total	
Across intrusives	NE	NW	NE	NW	NE	NW	NE	NW	NE	NW	NE	NW
None cross	0	0	0	0	0	0	0	0	0	1	0	1
Partial	4	1	3	2	2	1	3	6	2	0	14	10
Through	2	1	2	0	1	2	3	0	0	0	8	3
Boundary	0	1	2	3	4	3	1	0	0	0	7	7
Totals	6	3	7	5	7	6	7	6	2	0	29	20

$Chi^2=1.33$

E=0.16

GARFIELD HILLS

Imagery U-2 scale

	NE	NW	NE	NW	NE	NW	NE	NW	NE	NW	NE	NW
None cross	0	0	0	0	0	1	0	0	0	1	0	2
Partial	4	7	4	1	3	0	9	1	1	0	21	9
Through	1	1	1	1	0	0	1	0	1	0	4	2
Boundary	1	0	1	2	0	0	0	0	1	0	3	2
Total	6	8	6	4	3	0	10	1	3	0	28	15

$Chi^2 1.33$

E=0.14

SAND SPRINGS-Landsat E 1397-18051-5 scale 1:250,000

	Intru W of SS		Sand Spring		Wonder/Eagle		Total	
	NE	NW	NE	NW	NE	NW	NE	NW
None cross	1	0	0	0	0	0	1	0
Partial	0	4	5	6	1	0	6	10
Through	0	0	0	1	3	1	3	2
Boundary	0	0	0	1	1	2	1	3
Total	0	4	5	8	5	3	10	15

$Chi^2=1.25$

E=0.22

SAND SPRINGS Photo Index 1:52,000 Nev Bur of Mines Map Folio, Shoal Event

	NE	NW	
None cross	-	-	$Chi^2=0.11$
Partial	24	19	E=0.05
Through	1	1	
Boundary	4	4	
Total	29	24	

Table 4 Contingency tables to test preference of NE or NW trending lineaments across intrusives in SW Nevada

Chi-square was below the number required to indicate a significant difference (see Table 4).

The total length of lineaments across the intrusives was also measured for each overlay of the Toiyabe and Toquima Ranges (Table 5). This count shows that north-south and east-west trending lineaments have twice as many kilometers of length as the northeasterly and northwesterly trending lineaments. There is no appreciable difference in the lengths of the northeasterly and northwesterly trending lineaments.

The total number of lineaments across the intrusives (Table 5) shows that there is a nearly equal number of lineaments in the northeasterly (169) and the northwesterly (154) directions.

It is concluded that there is no significant difference in the number or length of northeasterly and northwesterly trending lineaments across intrusions in the area studied. The presence or absence of these lineaments cannot be used as a tool for locating intrusives using Landsat imagery.

c. Arcuate lineaments as indicators of intrusive doming

Wisser (1960), Wertz (1968), and other authors have suggested that intrusions cause, or are found in, domal structures which are accompanied by radial and concentric fracturing. Radial fracturing was eliminated as part of the present study because of the great complexity of linear features visible on Landsat imagery. To find if arcuate lineaments might point to intrusions at their centers, lineaments were traced from the 1:500,000 scale prints of E-1451-18040-5 (including the Toiyabe and Toquima Ranges), and E-1306-17592-5 (including the Battle Mountain and Fish Creek Mountains in central Nevada). (C-1 and C-2 on location map, figure 23).

The arcuate lineaments were mapped as alignments of natural geomorphic features which form a segment of a regular curve. The lineament must be at least 75% topographic; it may follow faults, drainages, range boundaries, sharp tonal or textural boundaries, and alluvial fans where the edge of the fan is in line with other geomorphic features.

Forty-two arcuate lineaments were traced in the Toiyabe and Toquima Ranges, and 22 in the Battle Mountain-Fish Creek ranges.

Intrusive		Azimuth of Lineaments							
		68-88°W	43-68°W	43-18°W	18 W-2°E	2-22°E	22-47°E	47-72°E	72-92°E
Toiyobe R	1	18km	35km	23km	22.5km	27km	28km	14km	10km
	2	12	0	5	17	0	0	15	0
	3	13	5	0	0	8	0	5	10
	4	10	0	0	0	36	0	2	3
	5	12	0	0	0	14	0	2	0
	6	6	0	9	0	5	0	3	4
Toquima R	1	2	8	5	3	11	0	0	6
	2	0	0	0	0	0	9	0	0
	3	69	26	20	38	52	21	30	65
	4	20	0	12	0	15	2	0	14
Total		162	74	74	70.5	168	60	71	112

Length of lineaments across intrusives(in km) from Landsat Imagery.

Intrusives	NE	NW	Imagery
Garfield Hills[1]	29	20	Landsat 1:250,000
"	27	15	U-2
Sand Springs Intru[1]	5	8	Landsat 1:250,000
Intru W of Sand Spr[1]	0	4	"
Wonder-Eagleville set[1]	5	3	"
Sand Springs[1]	29	24	Photo Index 1:500,000
Toiyabe Range[2]	43	42	Landsat 1:500,000
Toquima Range[2]	34	38	"
Total	169	154[†]	NE & NW lineaments crossing intrusives

*1 Geol Map of Nevada 1:500,000
2 Geol Map of Mineral Co.Nevada; 1:250.000

Table 5 Number of lineaments across intrusions (N 20-70° E; N 20-70° W) Comparing different types of imagery

Part of the latter is shown on Figure 25. The centers were plotted geometrically and compared with the 1:500,000 scale Preliminary Geologic Map of Nevada. Figure 26 is a tracing of the faults, geologic boundaries and intrusions for the area of Figure 25. Seven of the 22 centers in the first study fell on or within 2 km of intrusions. Eight of the 42 centers in the second study fell on or within 2 km of intrusions. Three centers in the first study fell on mining districts; two in the second.

It is concluded that too few arcuate lineaments traced from Landsat imagery have centers of curvature which fall on intrusions to make this technique a useful primary prospecting tool for locating intrusive outcrops. No effort was made in this study to relate the centers to volcanic centers.

2. Alignments of Intrusions

a. Correlation of alignments of intrusions with lineaments

To find if alignments of intrusions correlate with single lineaments, three alignments each having twenty or more intrusions were examined. The first of these trends N 30^{o} E, in west-central Nevada; the second is a north-south alignment across in eastern Nevada, and the third an east-west alignment across north-central Nevada (see locations on figure 27 and Plate 3).

<u>Selection of lineaments</u>

Lineaments for this study were traced as sets, parallel or sub-parallel to the alignments of intrusions, from a 1:1,000,000 scale Landsat mosaic of Nevada. On this scale, lineaments can be traced for greater map distances as single straight lines (see study II-C-2). The lineaments selected have a minimum length of 10 km, and follow range front boundaries, drainages, faults, and other linear geomorphic features. Plate 3 shows the alignments of intrusives and the sets of related lineaments.

<u>Description of lineaments sets</u>

N 30^{o} E alignment: "A" on Plate 3 shows the locations of the intrusions and the lineaments parallel and sub-parallel to their alignment. This 250-km-long lineament lies within Battle Mountain on the north and crosses the Fish Creek, Augusta, Clan Alpine, and

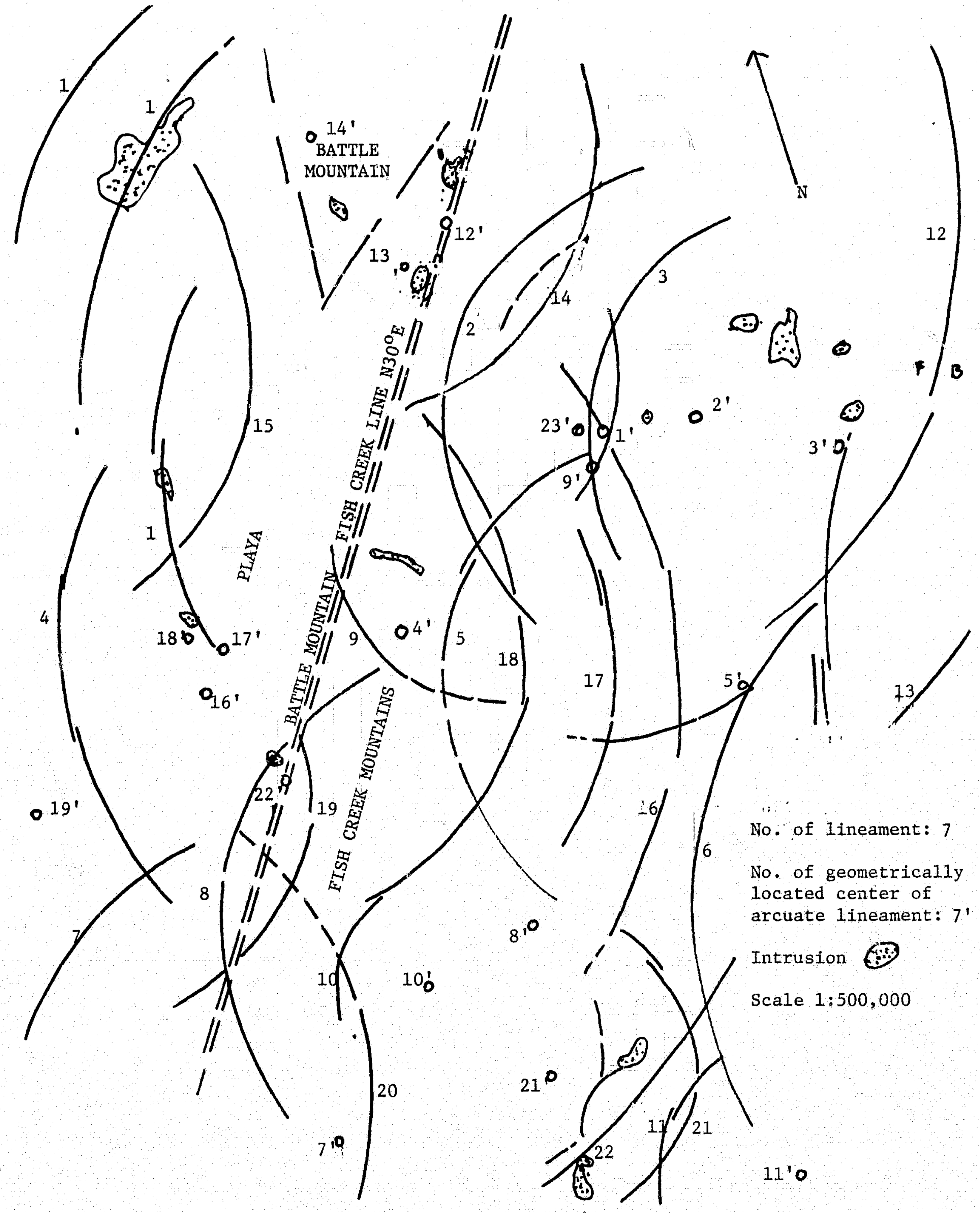


Figure 25: ARCUATE LINEAMENTS TRACED FROM LANDSAT IMAGERY
Along BATTLE MOUNTAIN-FISH CREEK ALIGNMENT OF INTRUSIONS

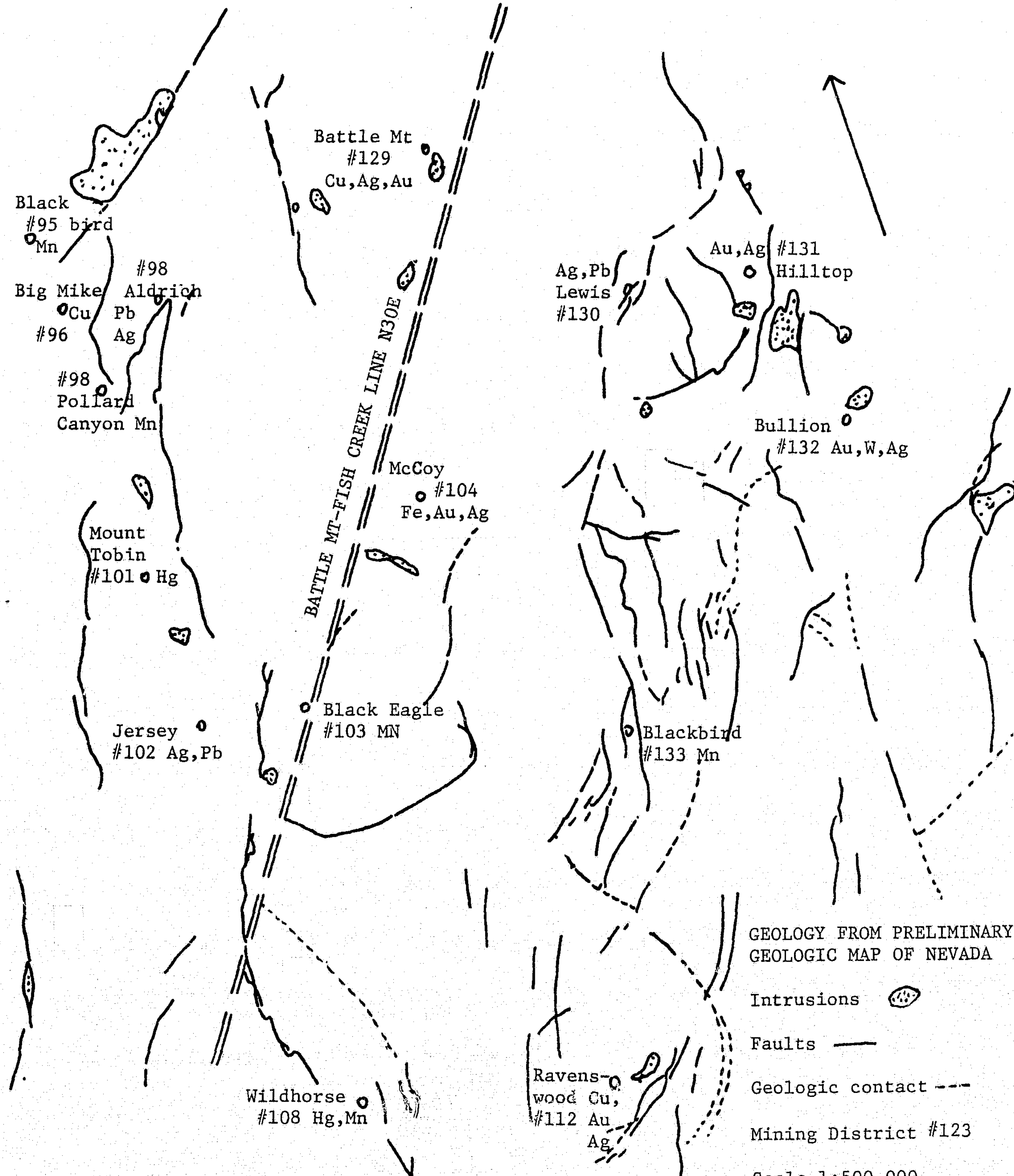
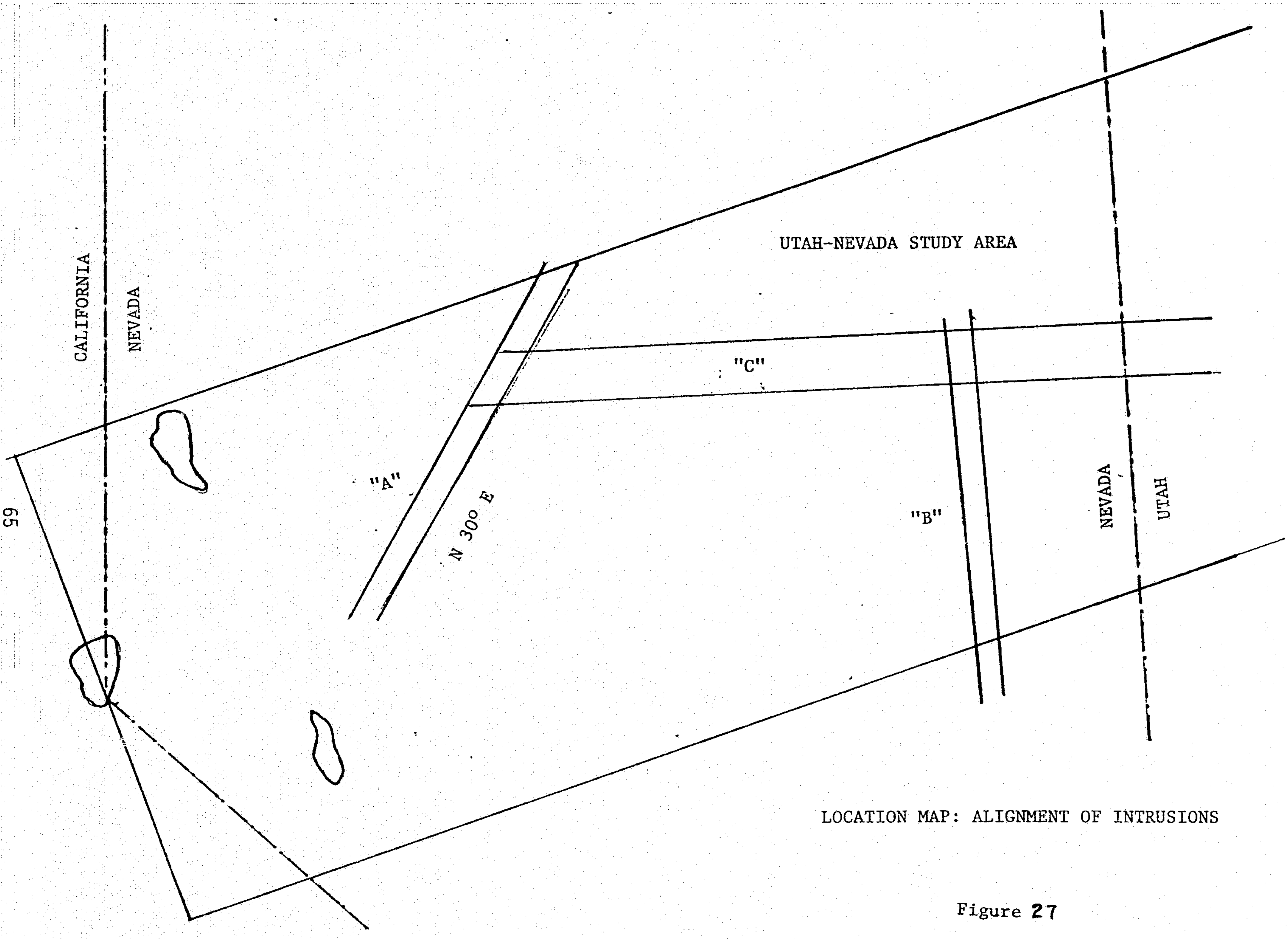


Figure 26: MAPPED FAULTS, CONTACTS, INTRUSIONS, AND MINING DISTRICTS
FOR AREA SHOWN ON FIGURE 25



LOCATION MAP: ALIGNMENT OF INTRUSIONS

Figure 27

Sand Springs Ranges to the southwest. Few lineaments were found that parallel the N 30° E intrusive alignment; and these lineaments cut across a more persistent N 25° E set of lineaments which follows the range outcrop pattern on western Nevada (see Plate 2, location of ranges in the study area). The N 30° E lineaments have a maximum length of 25 km and show apparent offsetting or dislocation.

North-South alignment: "B" shows the location of the 250 km alignment of approximately 20 intrusions in eastern Nevada. The alignment runs from Spruce Mountain on the north through the Egan Range to the south. There are only four small intrusives mapped in the ranges to either side (see Intrusive Map of Nevada, 1975). A persistent N 10° W lineament, broken into several slightly offset segments, bounds the west of the Cherry Creek Range at the north end, lies along the east of the Egan Range in its central part, and crosses to bound the western edge of the Shell Creek Range (to the east of the Egan Range), at the southern part of the alignment. This lineament splits the alignment of intrusives, with the intrusives to the east of it at its northern part and to the west at its southern part. There is no evidence that it has controlled the emplacement of the intrusion.

East-west alignment: "C" on Plate 3 shows the alignment of about a dozen clusters of intrusions across the ranges in east central Nevada from the Fish Creek Range on the west, through the Shoshone, Cortez, Ruby, Cherry Creek, Dolly Varden and White Horse Mountains in Nevada and Gold Hill in Utah. This alignment is about 225 km in length. No lineament set was found parallel to this alignment. Two sets of lineaments cross it at low angles: N 75-80° E and N 70-80° W.

In the Utah-Nevada study area, alignments of intrusions do not appear to lie along the lineaments mapped from the 1:1,000,000 scale Landsat imagery for this study. Two of the three alignments (A and B) which were compared with the lineaments closely parallel the range outcrop pattern and the lineaments related to the Basin and Range faulting; the third alignment of intrusions cuts across the range outcrop pattern (east-west alignment) and has no lineaments mapped along it or parallel to it. This suggests that the lineaments as mapped from Landsat imagery for this study do not have any direct

control of the emplacement of the intrusions.

b. Distribution of intrusions in Nevada

To find if there is a linear distribution of intrusions in Nevada, a study was made using the outcrop pattern on the Intrusive Map of Nevada (1975; scale 1:1,000,000).

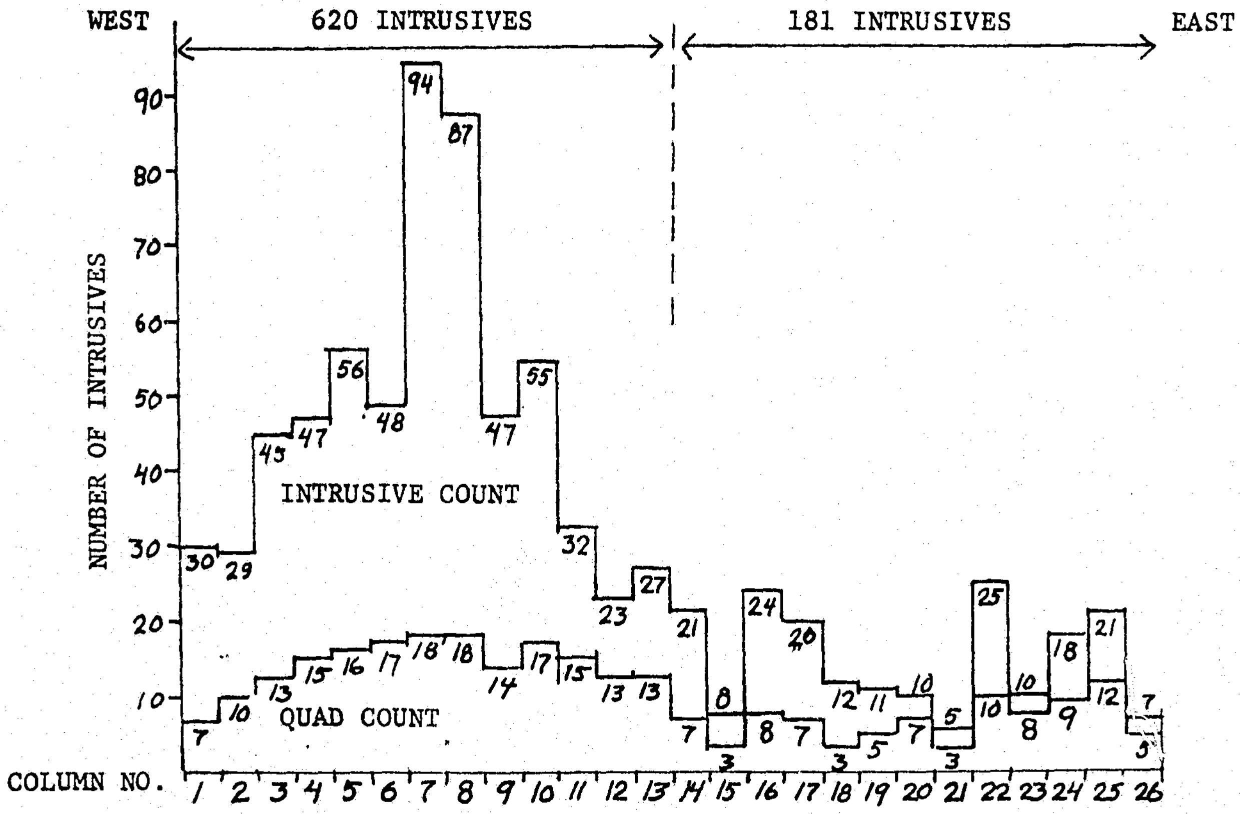
A rectangular grid with squares (quads) equivalent to 20 km on a side (from the formula 2 x total area/number of intrusions) was laid over the map of intrusive outcrops, north of latitude 38° N. Two counts were made, one with the grid oriented north-south; one with it oriented N 30° E, parallel to an alignment of intrusions studied in section II-D-2-a.

Histograms were prepared to show the number of intrusions in both vertical (north to south) and horizontal (west to east) columns. The upper curves on Figures 28-A and 29-A show the west to east count; the upper curves on Figures 28-B and 29-B show the north to south count. The lower curves on each figure show the number of 20 x 20 km quads containing one or more intrusive outcrops, to balance the wide discrepancy in area of the individual intrusive outcrops.

The upper curves of figures 28-A and 29-A shows the greater concentration of intrusions in the western part of Nevada. The intrusion count histograms show wide variation in the distribution of the intrusions, on both the north-south and N 30° E grid orientations, and in both the west to east and north to south directions. The variation in number of intrusions from one column to the next is at least as great in the north-south as in the west to east directions, suggesting that range outcrop pattern is not a controlling factor in their distribution.

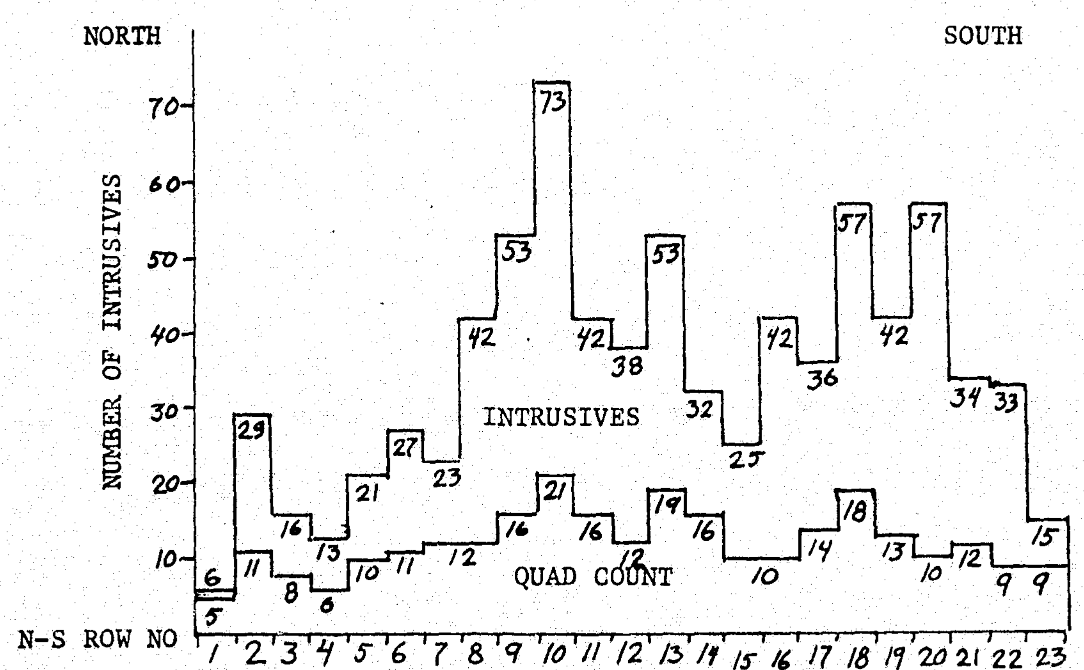
The use of the number of quads containing intrusions flattens the curves and again suggests that factors other than range outcrop patterns may control the outcrop pattern of the intrusions. Among these might be depth of exposure; a single large intrusion may be exposed as a single exposure or as a multitude of small outcrops.

There may be a linear distribution of the intrusive outcrops in Nevada, but the meaning of the results of the study are not clear.



A

INTRUSION COUNT: TOTAL NUMBER OF INTRUSIVES IN EACH COLUMN
WEST TO EAST
QUAD COUNT: NUMBER OF 23 POSSIBLE QUADS CONTAINING INTRUSIVES
QUADS 20 x 20 KM^2

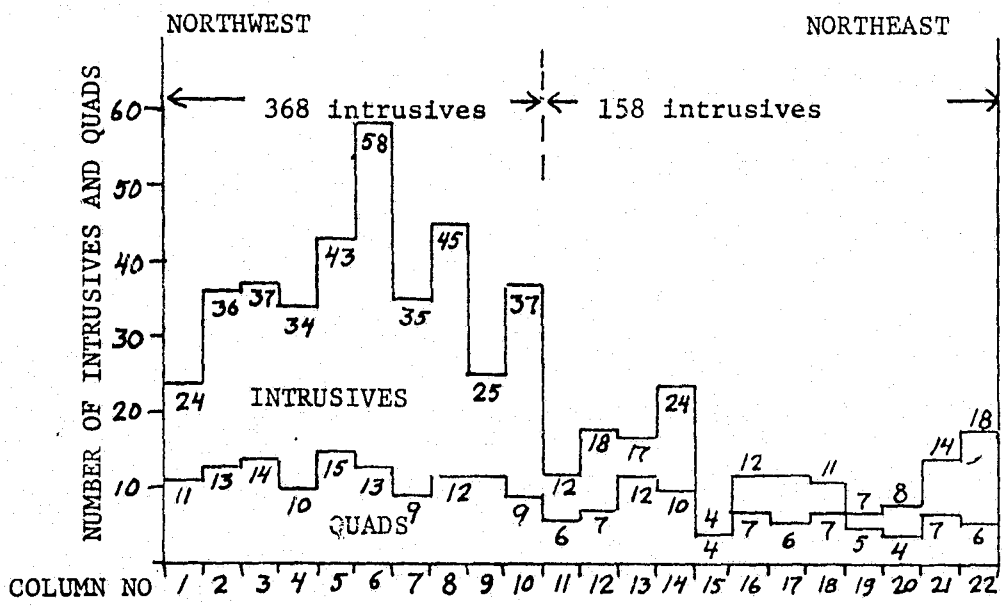


B

INTRUSION COUNT NORTH TO SOUTH

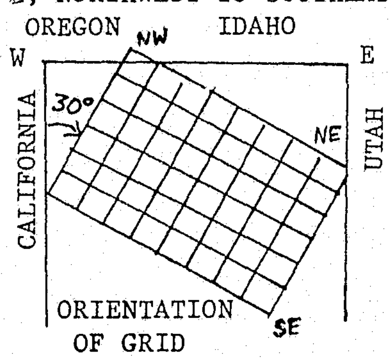
QUAD COUNT: NO. OF POSSIBLE 26 QUADS CONTAINING INTRUSIVES Figure 28

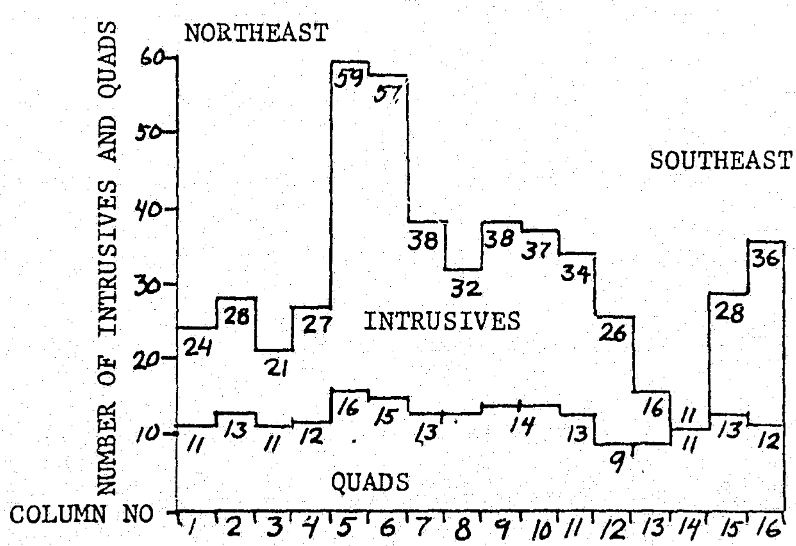
HISTOGRAMS OF INTRUSION COUNT: NORTH-SOUTH ORIENTATION



A INTRUSION COUNT WITH GRID ORIENTED N 30° E, NORTHWEST TO SOUTHEAST

QUAD COUNT OF POSSIBLE 16





B INTRUSION COUNT WITH GRID ORIENTED N 30° E, NORTHEAST TO SOUTHEAST

QUAD COUNT OF POSSIBLE 22

HISTOGRAMS OF INTRUSION COUNT: N 30° E ORIENTATION Figure 29

c. Outcrop count to test effect of Basin and Range outcrop pattern on intrusive alignments

To test the argument that the northerly orientation of the ranges controls the linearity of the intrusive outcrop patterns, the percent of outcrop area was determined for the six most easterly north-south columns, using the 20 x 20 km grid. Figure 30 is a histogram showing the percent outcrop and the actual intrusion count for each of these columns. There is no apparent correlation between percent of outcrop and either the number of intrusions or the number of 20 x 20 quads containing intrusions. Since adjacent ranges have significantly different intrusive counts, outcrop area alone appears to have no control over the distribution of the intrusions.

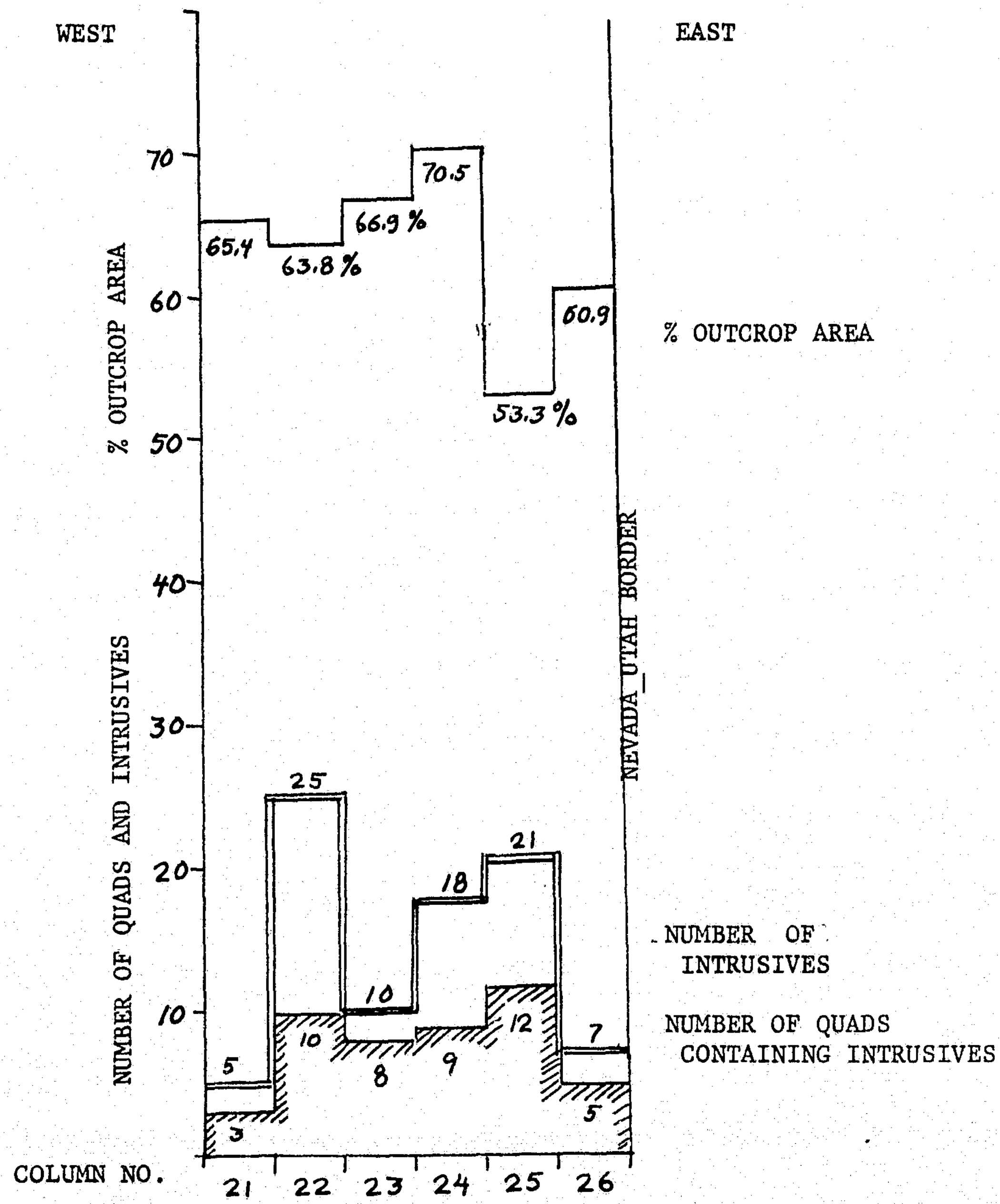
It is concluded that there may be some linear control of intrusive outcrops but it is not related to the present Basin and Range topography. Volcanics have been ignored in this study, but it is shown elsewhere in this report that many basalts are also found along lines defined by alignments of intrusions. This supports the idea that both intrusions and volcanism are controlled by deep fractures which however are not recognized as lineaments on the Landsat imagery.

E. Summary and Conclusions of Lineament Studies

To find if intrusions or mining districts can be located on Landsat imagery using photogeologic techniques, lineaments were selected from the imagery using several different sets of criteria. These criteria include minimum length, azimuth, and type of topographic expression. The criteria were set up to increase operator objectivity and to make the methods and results of these studies more readily duplicated. The lineaments thus selected have been tested for their correspondence with intrusive outcrops and with the locations of mines and mining districts.

Summary of results:

1. Correspondence of lineaments with intrusions.
   a. Lineaments within intrusions show no preferred azimuth.
   b. Intrusions contain as many lineaments as surrounding rock.
   c. Arcuate lineaments may reflect doming by intrusions but do not point to intrusive outcrops at center of doming.
   d. Alignments of intrusions do not follow any single recognizable



Comparison of outcrop area along columns of north-south grid

with number of intrusions in same area in NE Nevada

Figure 30

lineament.

   e. Intrusions in Nevada may have a linear distribution which is not necessarily related to the Basin and Range outcrop pattern.

2. Correspondence of lineaments with mines and mining districts.
   a. Alignments of mining districts do not lie along any single apparent lineament (within the study area).
   b. Mines do not appear to be preferentially located along lineaments mappable from Landsat imagery.
   c. Mines do not appear to be preferentially located along lineaments of a certain azimuth.
   d. There does not appear to be any consistency in the metals produced by mines along a single lineament.
   e. Lineaments appear to separate blocks of mineralized crust from adjacent barren crust within the ranges.
   f. Lineaments which are parallel to the mineralized structures within a mining district are not continuous across the district.

Conclusions

In the Utah Nevada study area, which lies within the Basin and Range province, the authors were unable to distinguish on Landsat imagery those lineaments which are related to mining districts and igneous intrusions, without prior knowledge of the geology.

No lineaments could be mapped from the Landsat imagery along alignments of intrusions or mining districts. Where a lineament can be traced across a mining district, it does appear to be related to the mineralized structures within the district. Lineaments which parallel mineralized structures may be found within the mining district, but these terminate within the district. Longer lineaments parallel to the mineralized structures may be boundaries of the mineralized block.

The longest and most persistent sets of lineaments within the study area include the Tertiary-Quaternary Basin and Range fault system.

The general lack of correlation that was found between lineaments and intrusions or mines and mining districts suggest that:

1. There may be only random correlation.
2. The lineaments which may have controlled emplacement of the intrusions and mineralization may not now be visible on Landsat imagery as continuous linear structures, in the tectonically active Basin and Range province. They may possibly have been overprinted or displaced by younger structures.

INTRUSIVE IDENTIFICATION FROM GEOMORPHIC FEATURES

The purpose of this portion of the study was to find if intrusions can be identified by means of geomorphic features, including drainage patterns, slope analysis, and tonal patterns on Landsat imagery.

A. Drainage Pattern Study

To find if it is possible to distinguish intrusives from surrounding country rock by means of drainage patterns, three areas of intrusive outcrop were selected which had both Landsat and U-2 coverage. These area included the Whistler Mountains in Eureka County, Nevada (A-1 on Figure 31); the northern Stillwater Range, Churchill County, Nevada (A-2 on Figure 31); and the Sand Springs Range, Churchill County, Nevada (A-3 on Figure 31).

Drainage patterns were traced from the U-2 imagery, using a stereoscope, and from Landsat prints. The areas were compared with the geological maps of Eureka and Churchill Counties, Nevada, to determine the outcrop boundaries of the intrusions.

Comparisons of the drainages within the intrusives with those in the host rock areas around the intrusives indicated that the lithology appeared to have little, if any, control of the drainage patterns. Slope angle and form had a closer relationship to the drainage than did the lithology. The same drainage patterns occurred in both intrusives and sediments where the range front was steep, as in the Whistler Mountains (figure 32). Similar parallel drainages occurred on the back and dip slopes in both intrusive and sediments.

In the Stillwater Range (figures 33 and 34) there was no observable difference in the drainage patterns across several different types of rock.

In the Sand Springs Range (figure 34) there was a distinct difference in the drainage patterns in intrusive and surrounding rocks. Here the intrusive rock appears to be much harder than the surrounding Jurassic volcanics, so the rock type may control the relief as well as the drainage patterns.

It is concluded that the drainage patterns visible on Landsat appear

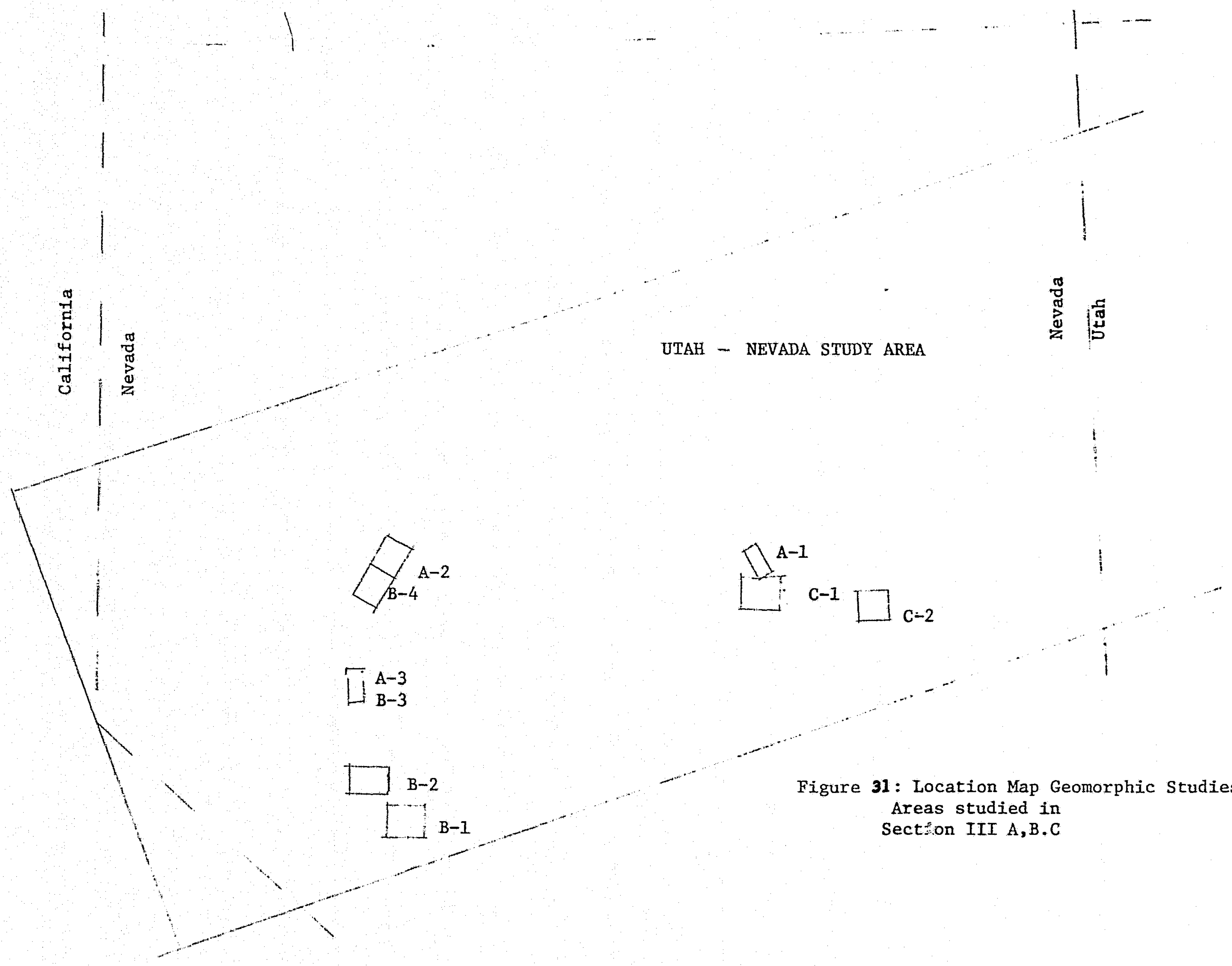
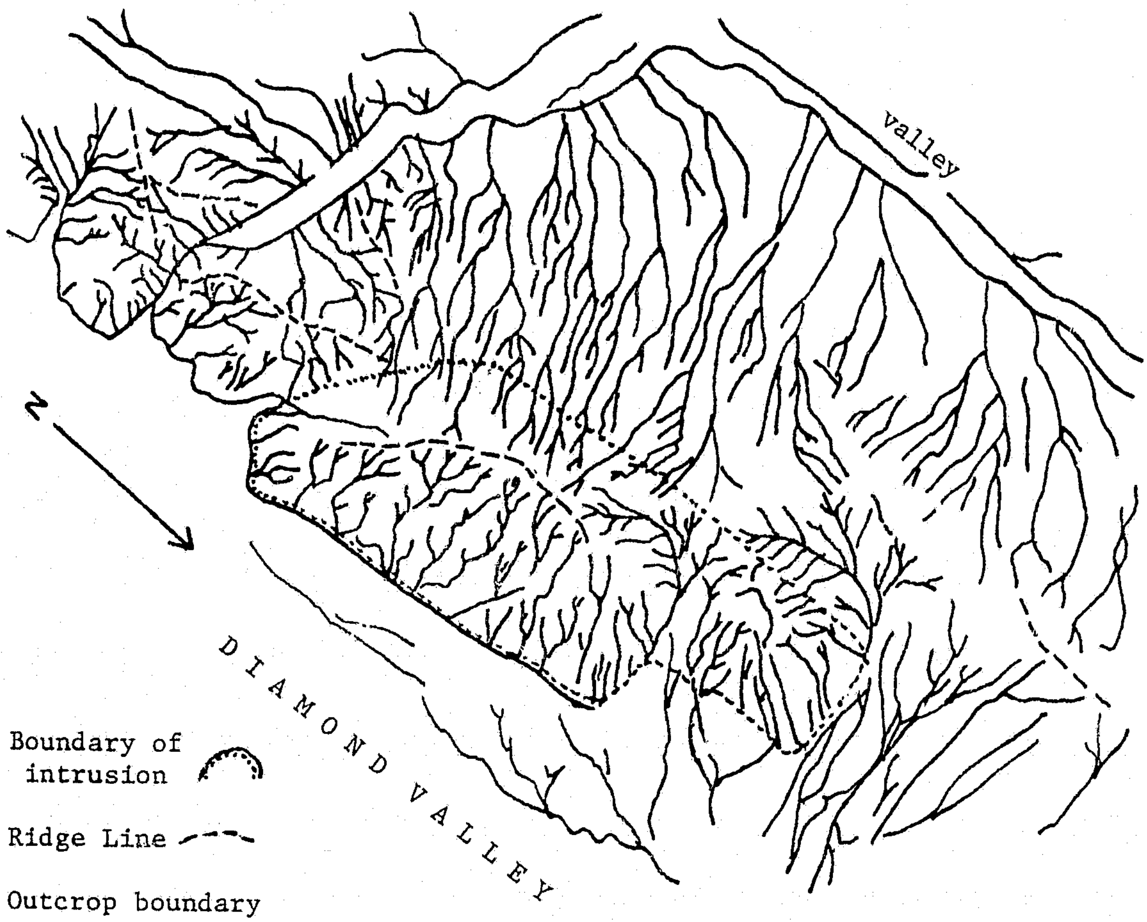
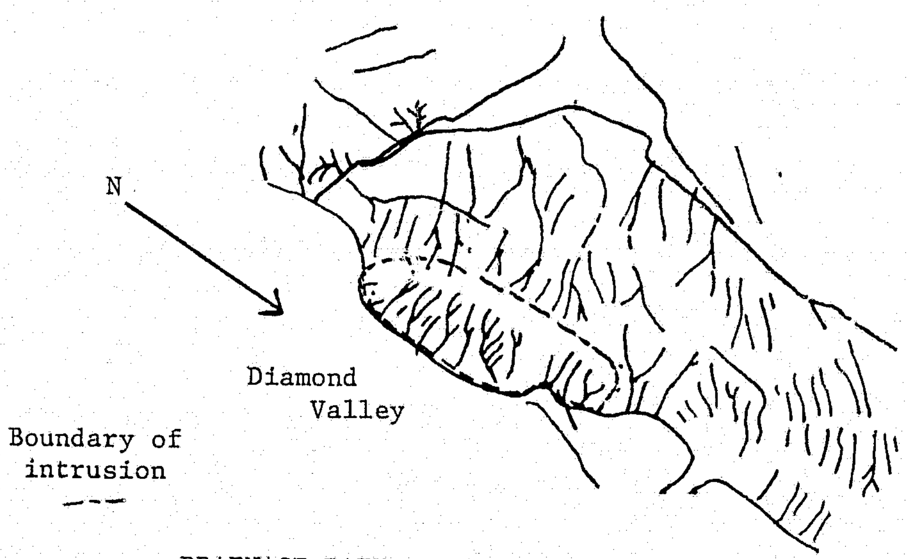


Figure 31: Location Map Geomorphic Studies
Areas studied in
Section III A,B.C



DRAINAGE PATTERNS FROM U-2 IMAGERY Scale 1:125,000



DRAINAGE PATTERNS FROM LANDSAT IMAGERY Scale 1:250,000

Figure 32: DRAINAGE PATTERNS IN WHISTLER MOUNTAIN, EUREKA CO., NEVADA

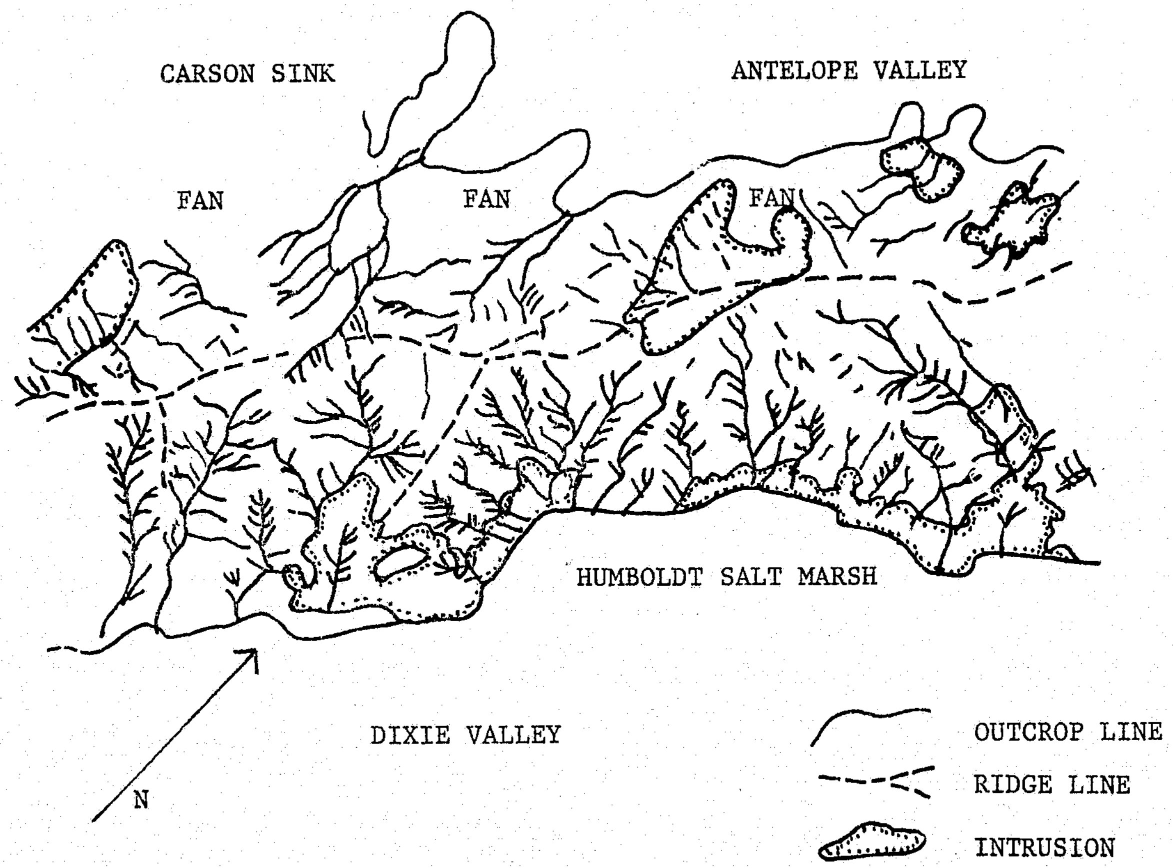
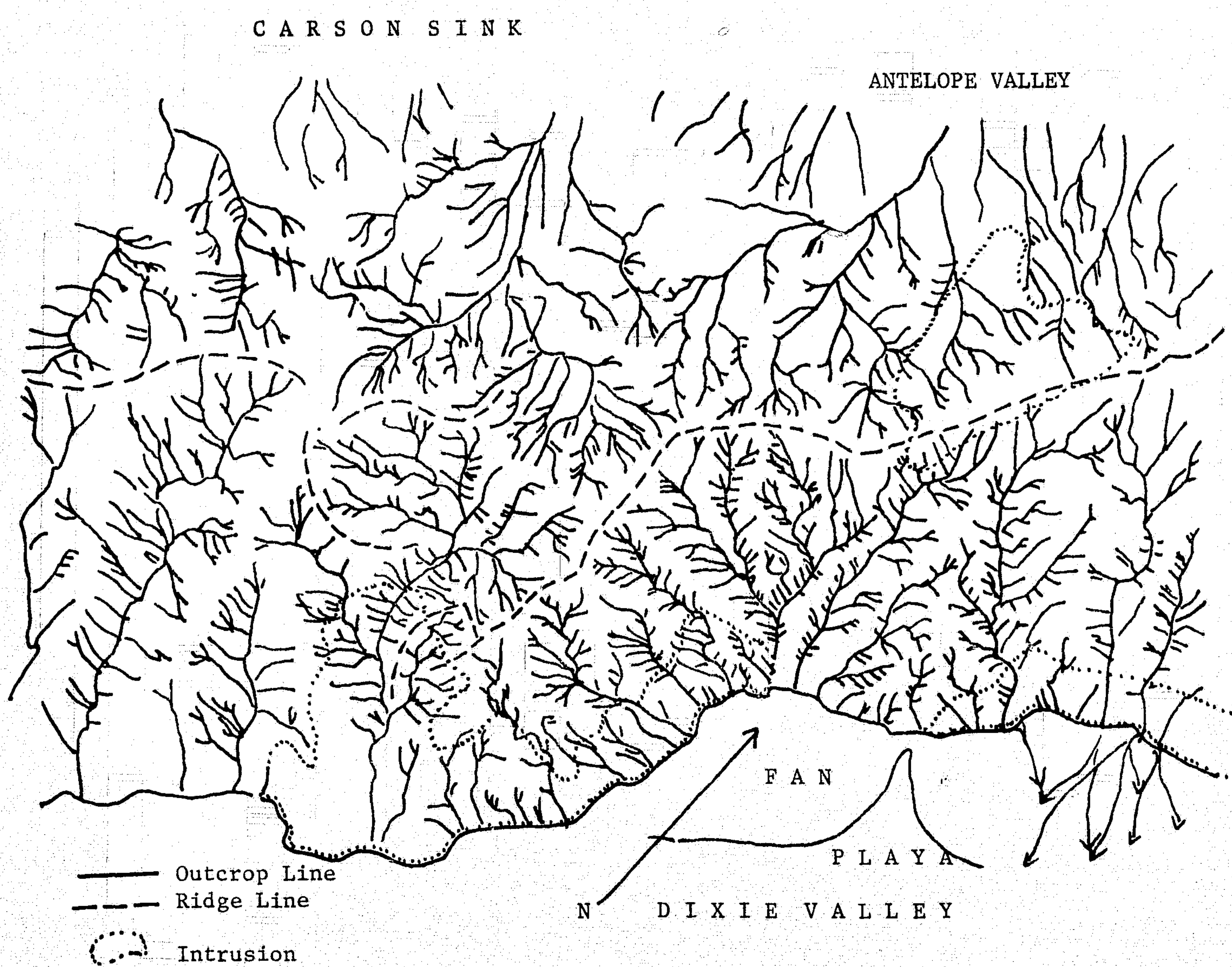
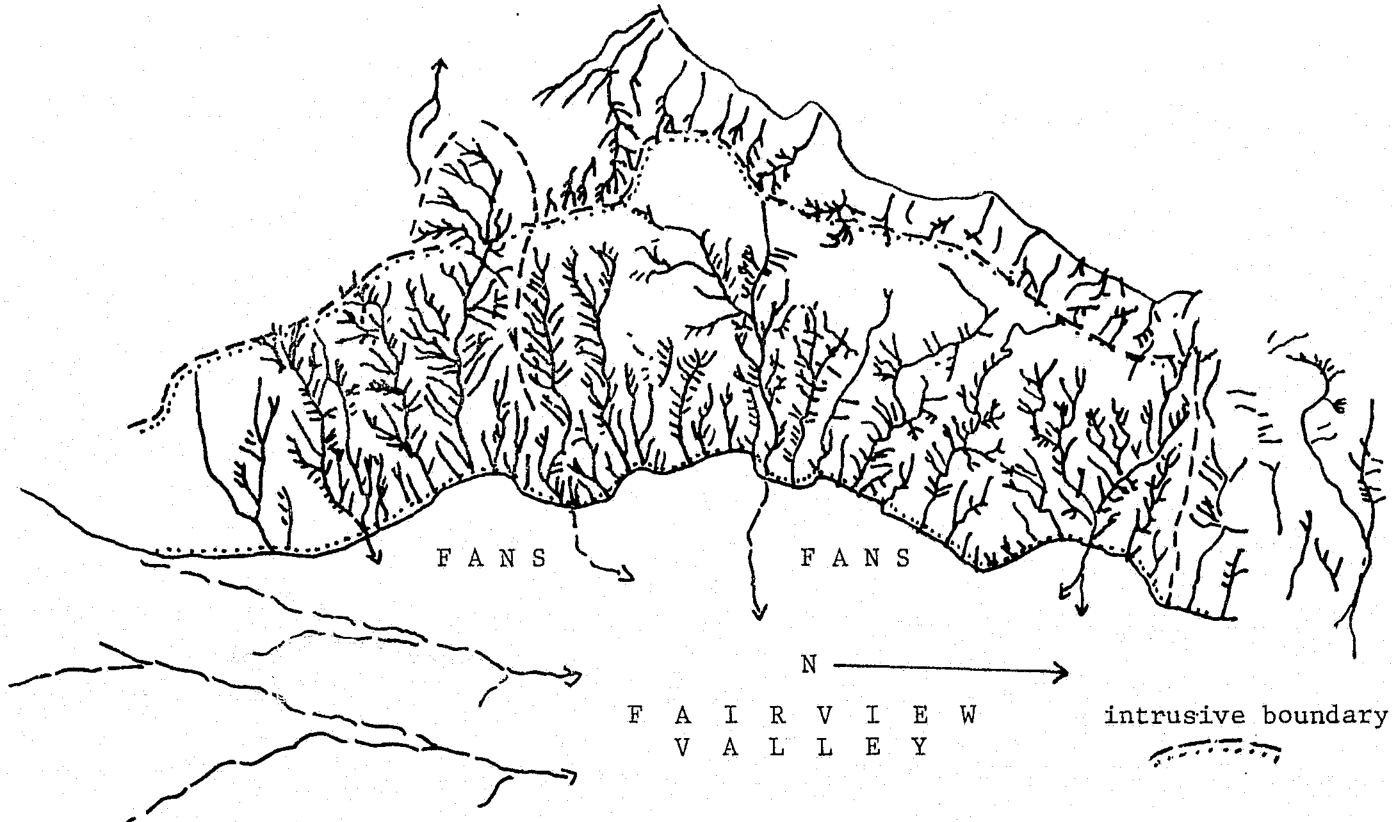


Figure 33: DRAINAGE PATTERNS IN NORTHERN STILLWATER RANGE, CHURCHILL CO., NEV.
From LANDSAT E 1793-17543-5 Scale 1:250,000
Geology from Geologic Map of Churchill co., Nevada

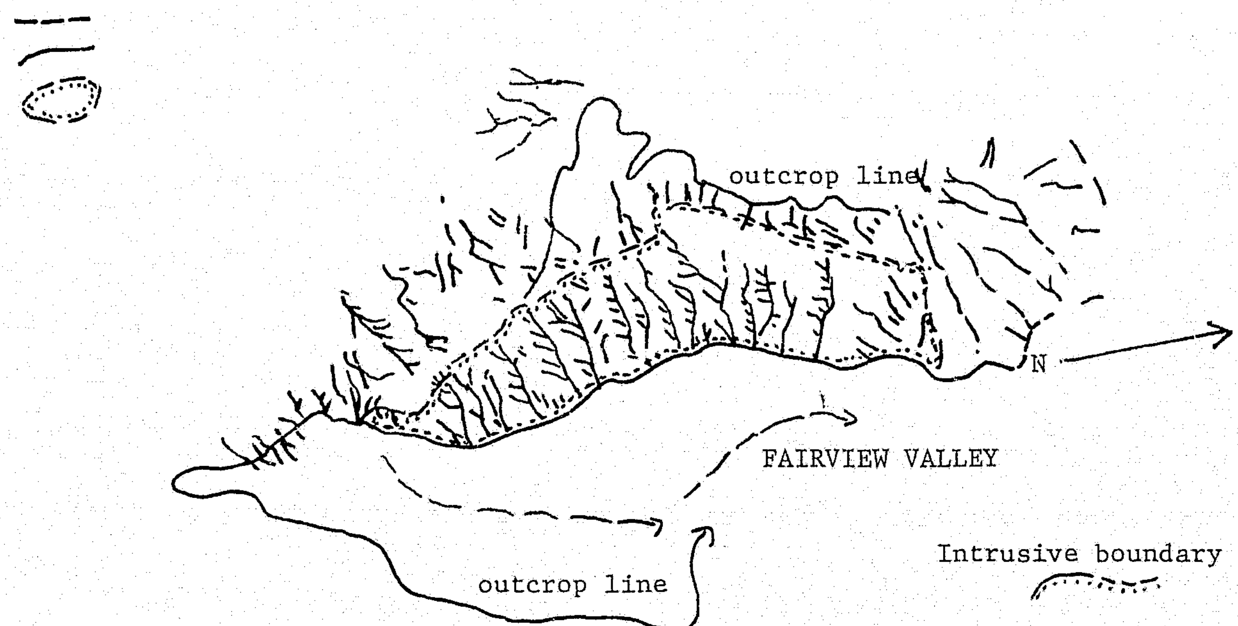


Scale 1:125,000
Drainage patterns from U-2 color transparencies
Geology from Geologic Map of Churchill Co., Nevada

Figure 34: DRAINAGE PATTERNS, NORTHERN STILLWATER RANGE, CHURCHILL CO., NEVADA



DRAINAGE PATTERNS IN THE SAND SPRINGS RANGE, MINERAL CO., NEVADA
FROM U-2 IMAGERY SCALE 1:]25,000



DRAINAGE PATTERNS IN SAND SPRINGS RANGE, MINERAL CO., NEVADA
From LANDSAT E 1397-18051-5 Scale 1:250,000
Location of intrusion from Geologic Map of Mineral Co., Nev.

Figure 35: Drainage Patterns, Sand Springs Range, LANDSAT and U-2 imagery

to be controlled by slope and relief as much as (or in spite of) lithology. They do not appear to be a valid tool for distinguishing intrusions from other rock types. In some cases the intrusion, if previously identified, might be mapped (for example, the Sand Springs Range) but the original identification cannot be made by drainage pattern alone.

B. Slope Studies

To find if intrusions could be identified from the form of the slopes (cross or along valley) developed in them, drainages were located on four intrusions on U-2 color positive transparencies with the use of a stereoscope. The areas of intrusive outcrop were determined from comparison with geologic maps of Churchill and Mineral Counties, Nevada. The areas tested were: the northeastern intrusion in the Garfield Hills, in Mineral Country, Nevada (B-1 on figure 31, and figure 36); the eastern portion of the intrusion in the Gillis Range, north of the Garfield Hills (B-2 on figure 31, and figure 37); the Sand Springs Range, in Churchill County (B-3 on figure 31, and figure 38); and the intrusion in the central Stillwater Range (B-4 on figure 31, and figure 39).

All drainages across the intrusions and some to either side within the country rock were plotted. The form or shape of slopes (concave, convex, concavo-convex, or straight) were determined for each major drainage line. The shapes of the interstream ridges were also noted. Valley cross sections at mid-stream were plotted for each drainage line.

Tabulations of these data were made to compare the slope shapes within intrusions with those in adjacent rock types, and a comparison of slope shapes was made for the drainages on north, south, east, and west slopes (Table 6). No notable preference was found for either concave or convex slopes within the intrusive rocks. Both types occur within both intrusive and surrounding country rock.

To find if the orientation or direction of drainage flow had any influence on the slope form, stream valleys were sorted accordingly (B on Table 6). Because of the north-sourth orientation of the ranges, the greater proportion of the drainages flow east or west. Again no particular slope form was found to correlate with any particular slope direction.

In the areas studied, nearly all drainages have V-shaped bottoms, regardless of rock type or slope direction.

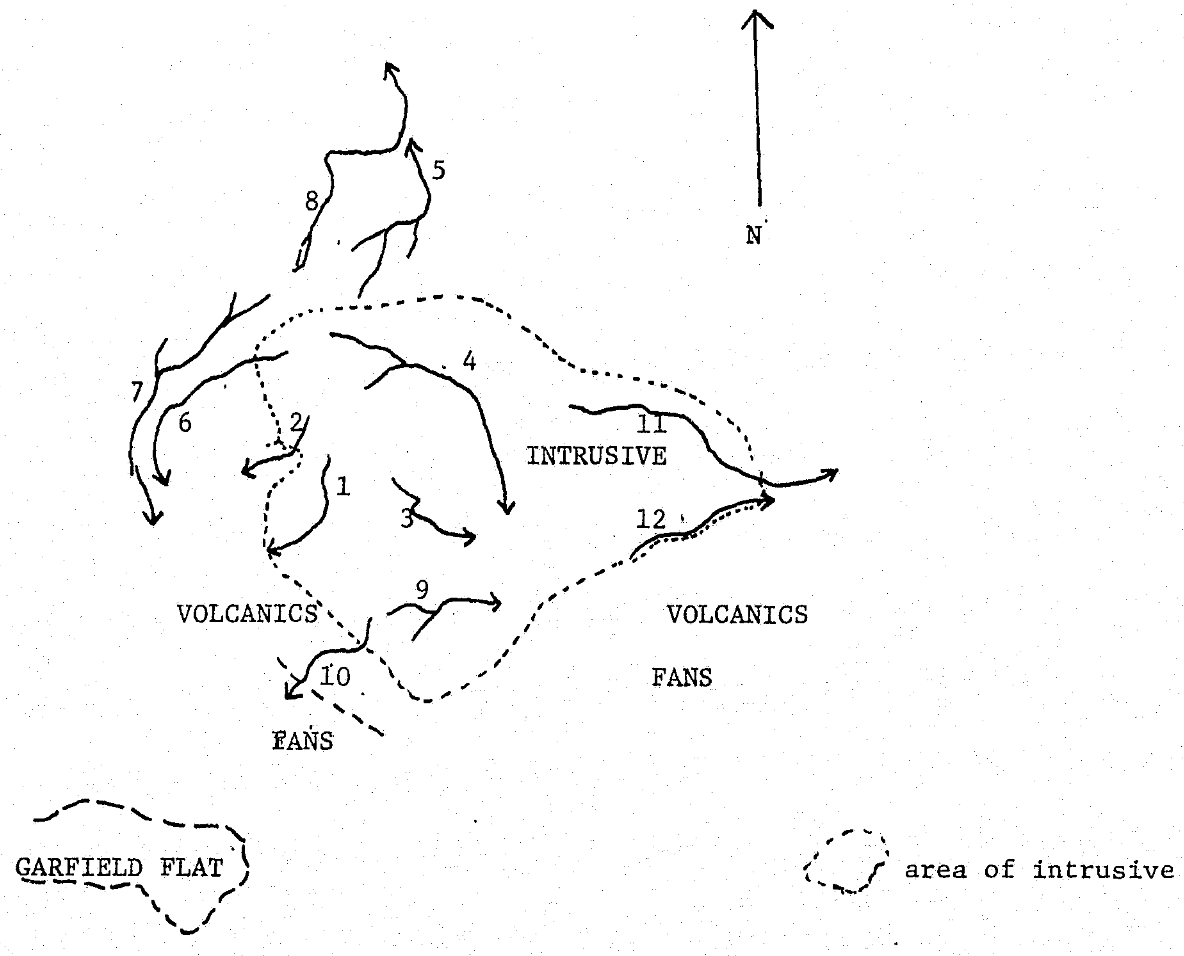


Figure 36: LOCATIONS OF DRAINAGES FOR SLOPE SHAPE STUDY
GARFIELD HILLS, MINERAL COUNTY, NEVADA
Geology from Geologic Map of Mineral Co., Nev.
Drainages from U-2 Frames UagII 3026
Scale 1:125,000

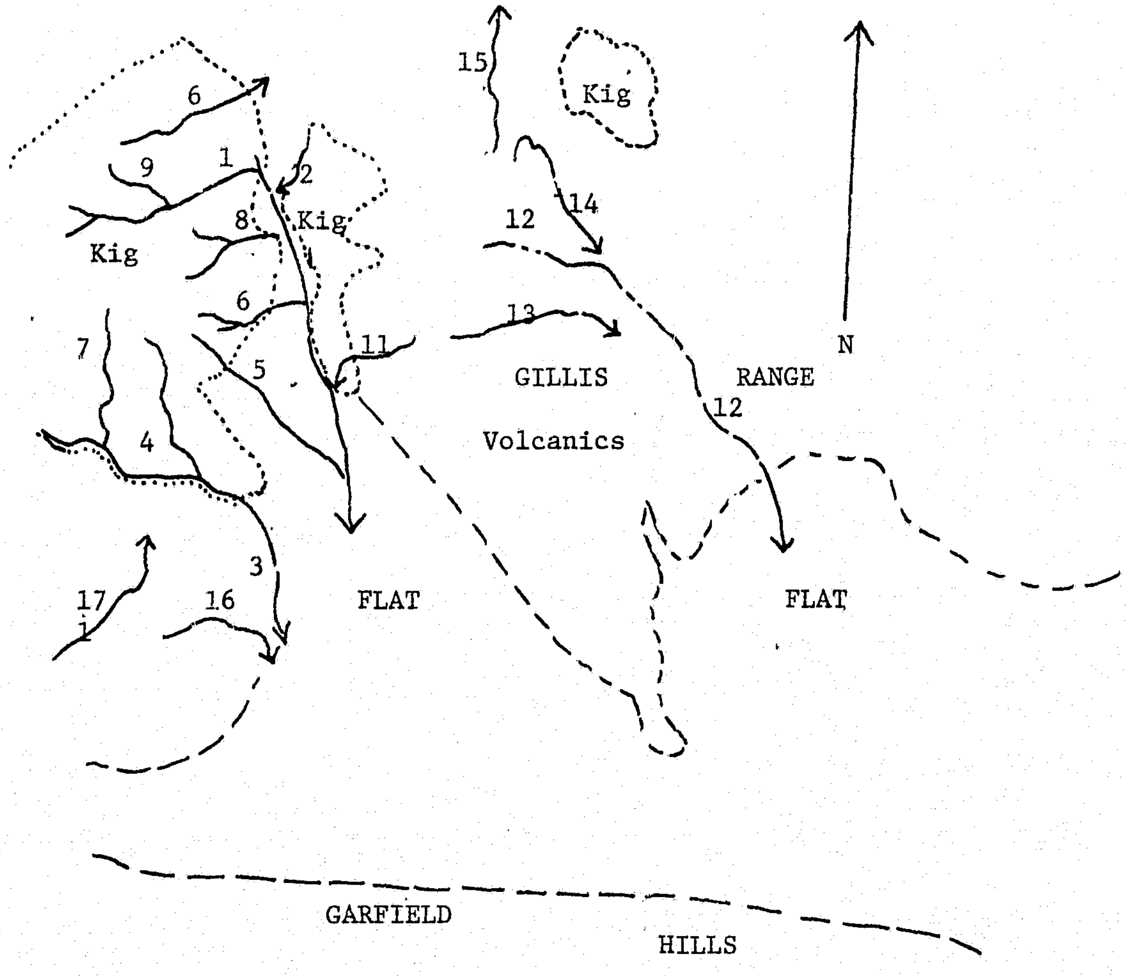


Figure 37 LOCATIONS OF DRAINAGES FOR SLOPE STUDIES IN GILLIS RANGE (NORTH of Garfield Hills) Mineral County, Nevada
From U-2 Color positive stereo pairs Frames 5493 and 5494
Scale 1:125,000 Geology from Geologic Map of Mineral County

---- Range front

Kig Intrusive boundary

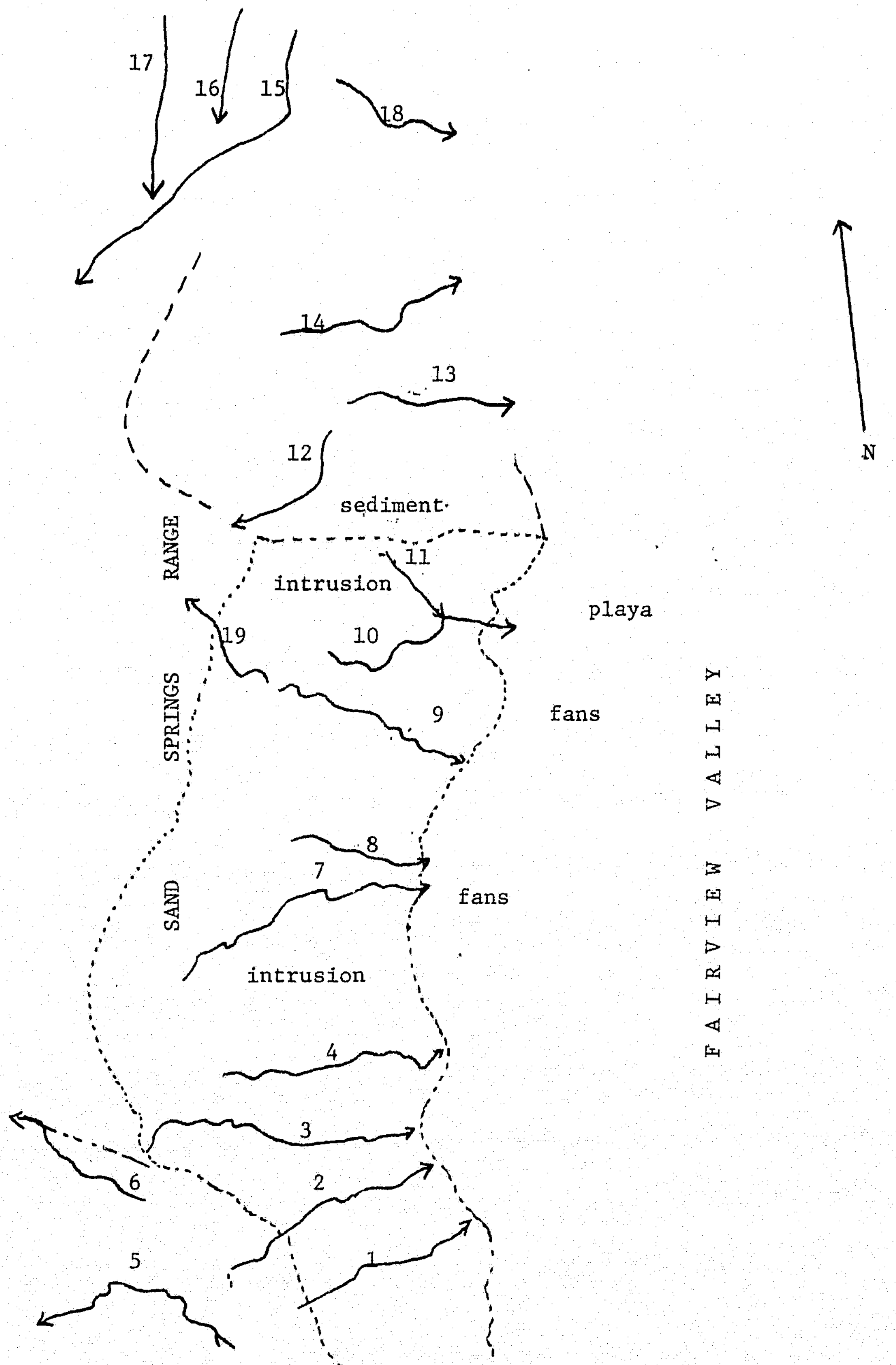


Figure 38: LOCATIONS OF DRAINAGES FOR SLOPE SHAPE STUDY, SAND SPRINGS RANGE
Churchill County, Nevada Scale 1:125,000
Drainages from U-2 Frames 5487-5488
Geology from Geologic Map of Churchill Co., Nevada

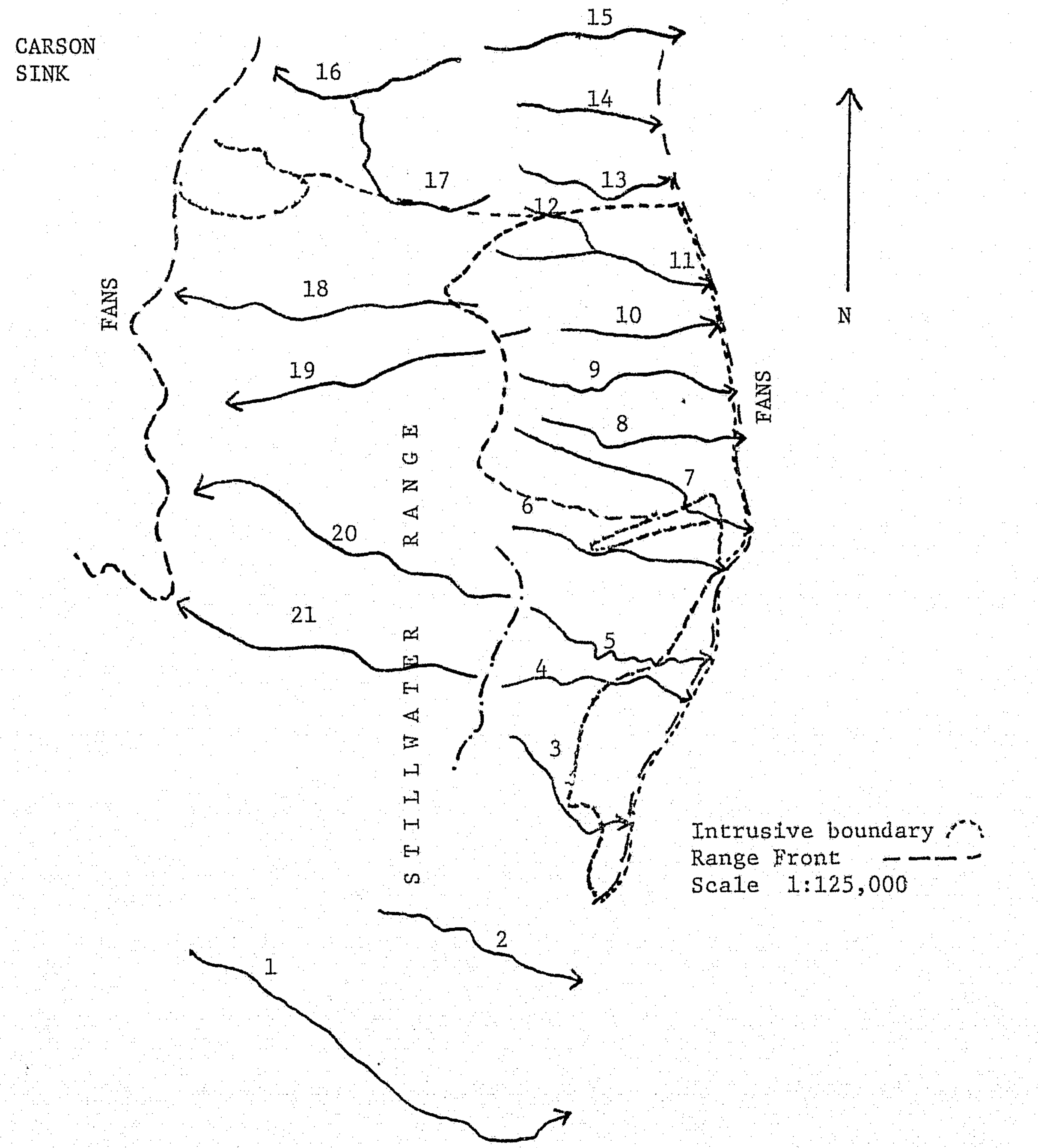


Figure 39: LOCATIONS OF DRAINAGES FOR SLOPE SHAPE STUDY, STILLWATER RANGE
CHURCHILL COUNTY, NEVADA FROM U-2 FRAME %$*$
Geology from Geologic Map of Churchill County, Nevada

LOCATION	A. Rock Type: INTRUSIVE	OTHER	MIXED	B. Slope Direction of Drainage: EAST	WEST	NORTH	SOUTH
GARFIELD HILLS	V VC C C CVC C	C C C C	V VC	VC C C C CVC C	C	C C C	C C C VC
GILLIS RANGE	C CV Irreg V C CV C	C C CVC C VC C	CVC C C C	C C C C VC	CVC C	C	CV CVC Irreg V CV C
SAND SPRINGS RANGE	C C VC CV C CV C C S	CVC C V VC CV VC C C C	C	C CV CVC Irreg C	C C V C CV C C CVC	C	C C C VC C
STILLWATER R	Irreg CV CVC CV C C CV	C CV CV CV C C CV CV C C C	C CV VC VC	C C VC VC VC Irreg CV CVC CV C C CV CV CV CV	C C CV C C C		
Total Number of Drainages	29	30	10				

A. Drainage Slope Shapes in Intrusives and Surrounding rocks
B. Drainage Slope Shapes according to Slope Direction

C = Concave
V = Convex
CV= Concavo-convex
VC = Convex-concave
S = Straight
Irreg = Irregular

Table 6: DRAINAGE SLOPE SHAPE ANALYSIS

It was concluded that drainage slopes do not appear to show any shape clearly related to rock type. Neither cross stream profiles nor interstream ridge profiles appeared to show any systematic relationship to rock type.

Because a stereoscopic study of the slopes visible on U-2 imagery gave negative results, and because the slopes are more clearly visible on the U-2 imagery than they are on Landsat, no detailed slope studies were made on Landsat imagery.

C. Tonal and Textural Boundaries

To find if mining districts could be distinguished from surrounding areas by tonal texture or contrast on Landsat imagery, areas of similar tone or texture were outlined by visual inspection for two areas, Eureka (C-1 on figure 31) and the White Pine Mining Districts (C-2 on figure 31), in Eureka and White Pine Counties, Nevada. Each area is about 25 km on a side.

Visual inspection was used in this study since it is the commonly used field mapping technique. Special techniques, such as density slicing and band ratioing, which may show more promising results, were not assessed in the current study.

All four bands of the Landsat Frame E-1755-17450 were visually inspected and Band 5, which showed the greatest contrast, was selected. The contrast may be at least in part due to summer vegetation, not visible on Band 7.

The resulting patterns (figures 40 and 41) correlated well with the geologic outcrop patterns of both districts, as compared directly with geologic maps of Eureka and White Pine Mountain Counties. However, no discernible separation of tone or texture could be found to distinguish the mineralized areas (as defined by the locations of the mines) from non-mineralized areas.

It was concluded that there did not appear to be any way to systematically distinguish mineralized rock from surrounding rock on Landsat imagery by inspection of tonal and textural contrast with the unaided eye.

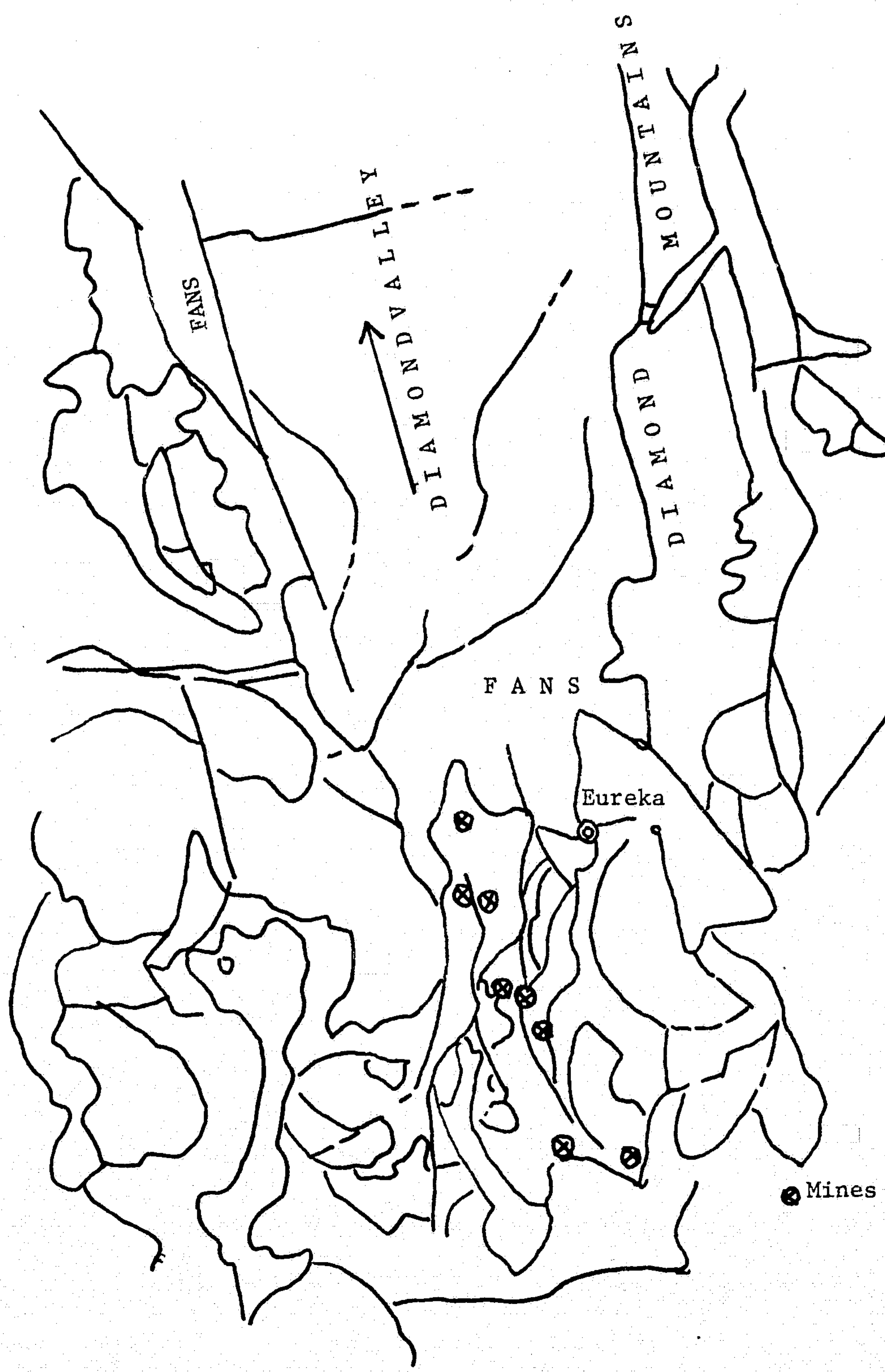


Figure 40: BOUNDARIES OF AREAS OF EQUAL TONE AND TEXTURE: EUREKA MINING DISTRICT, EURAKE COUNTY, NEVADA
Fron LANDSAT E-1755-17450-5 Scale 1:250,000

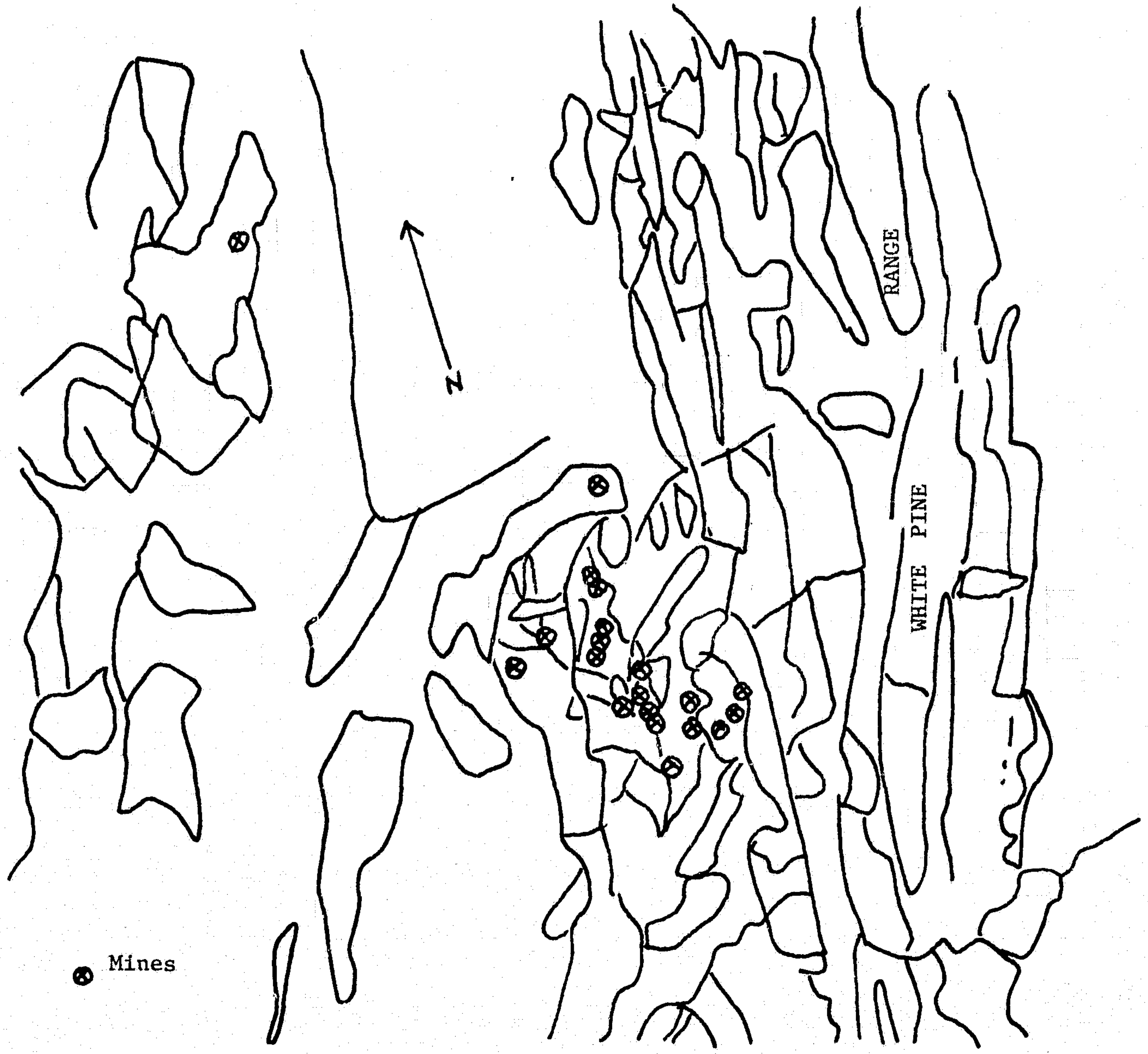


Figure 41: BOUNDARIES OF AREAS OF EQUAL TONE AND TEXTURE
WHITE PINE MINING DISTRICT, WHITE PINE CO., NEV.
From LANDSAT E-1755-17450-5   Scale 1:250,000

IV. VALLEY-STREAM/LINEAMENT ANALYSIS BY LENGTH AND AZIMUTH IN MINERALIZED AND NON-MINERALIZED LOCALITIES WITHIN SPECIAL STUDY AREA

A. Introduction

It was proposed that those stream courses or valleys whose length and azimuth could be reliably measured at the scale of Landsat imagery might serve to delineate "lineaments", i.e. regional fracture and/or fault traces. Further, if one or more preferred azimuths could be identified with trends of mineralization, these could be an aid in regional exploration for minerals.

The portion of the project area selected for this study (Fig.41A) p. 90 lies in the central portions of Lander and Eureka Counties, Nevada. Here surface strata consists of intensely folded eugeosynclinal (siliceous and volcanic) sediments, intruded by numerous acidic intrusives and blanketed over large areas by acidic tuffs. The area has been subjected to several episodes of thrust faulting. The present topographic form of alternating mountains and basins is fundamentally the result of normal faults whose activity continues into the present.

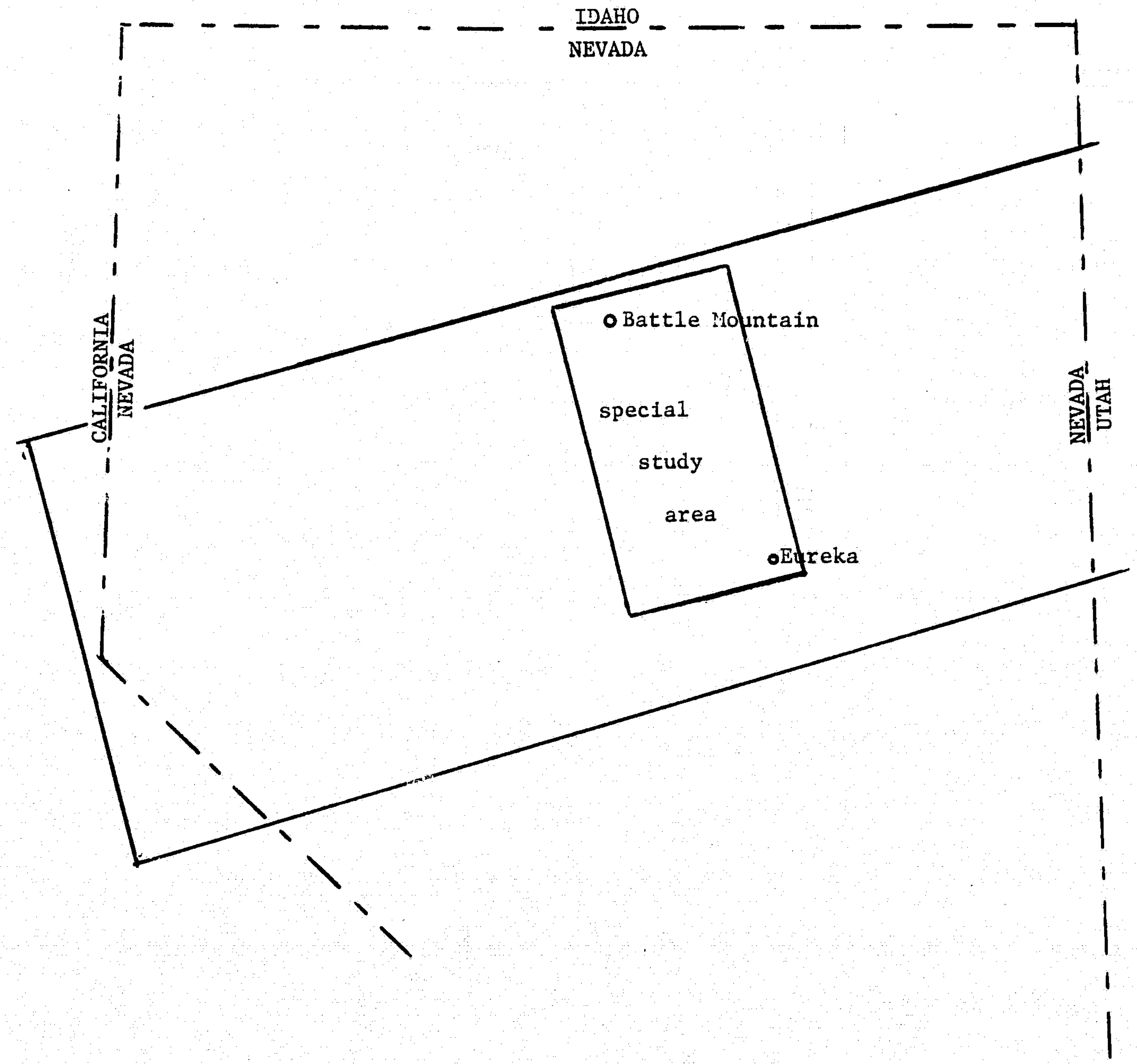
At least 21 base and precious metal mining districts have been located here. Twelve of these lie in an apparent northwest to southeast alignment named the Battle Mountain-Eureka trend, after towns located at its approximate termini.

B. Valley-Stream Lineament Orientations

As a first step in this portion of the study, valley-stream/lineament orientations of various length classes were compared within and adjacent to the mineralized trend (see Plate 5).

1. Method

Imagery on bands 5 and 7 from the 1:1,000,000 scale Landsat scene E-1072-17592 (p. 91), E-1396-17592 (p. 92), E-1719-17461 (p. 93) was examined on a Bausch and Lomb model ZT-4 transfer scope. The magnification was adjusted to conform to the 1:250,000 scale of the AMS sheets NK 11-11 (Winnemucca), NJ 11-2 (Millett), and NJ 11-3

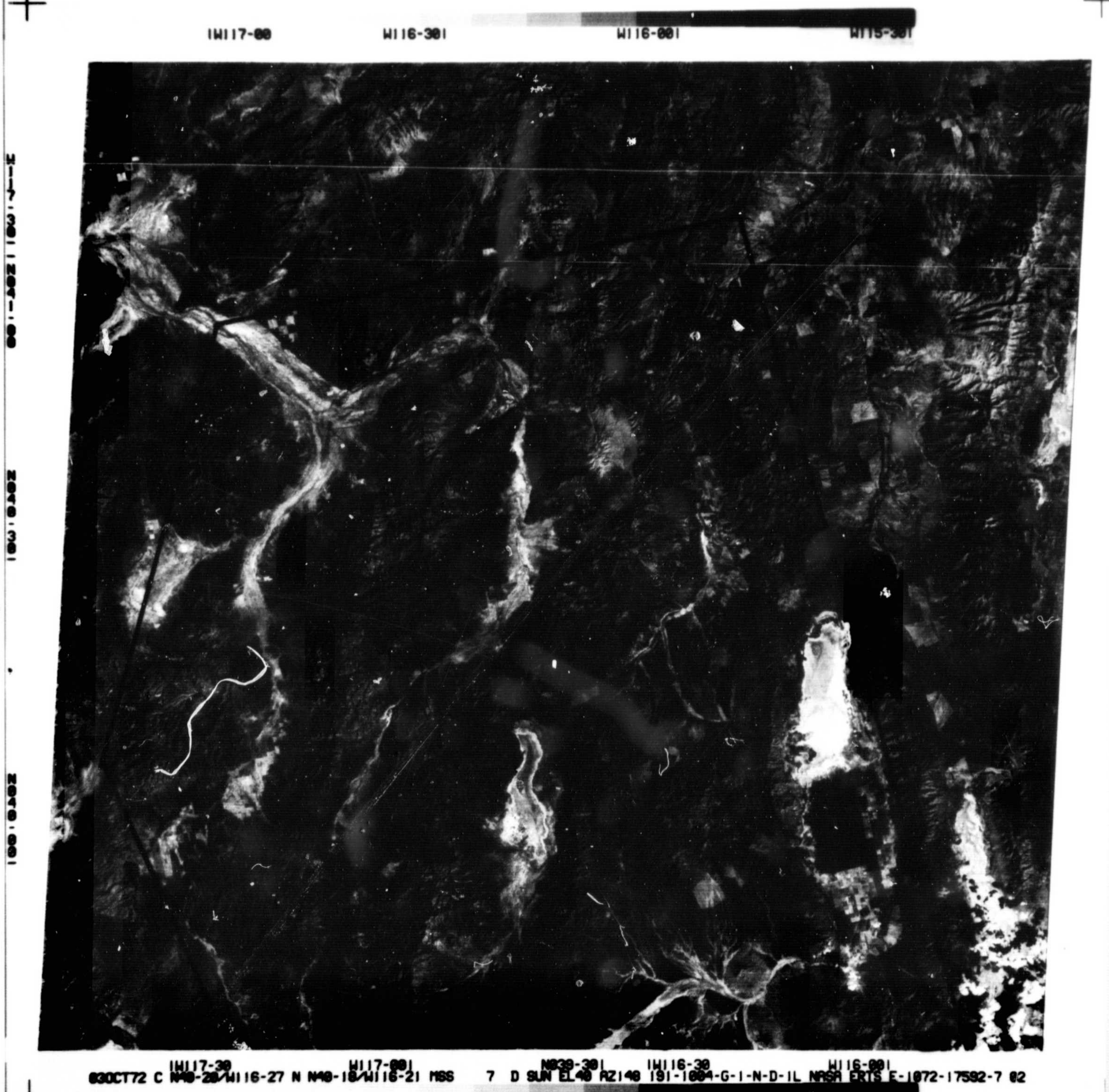


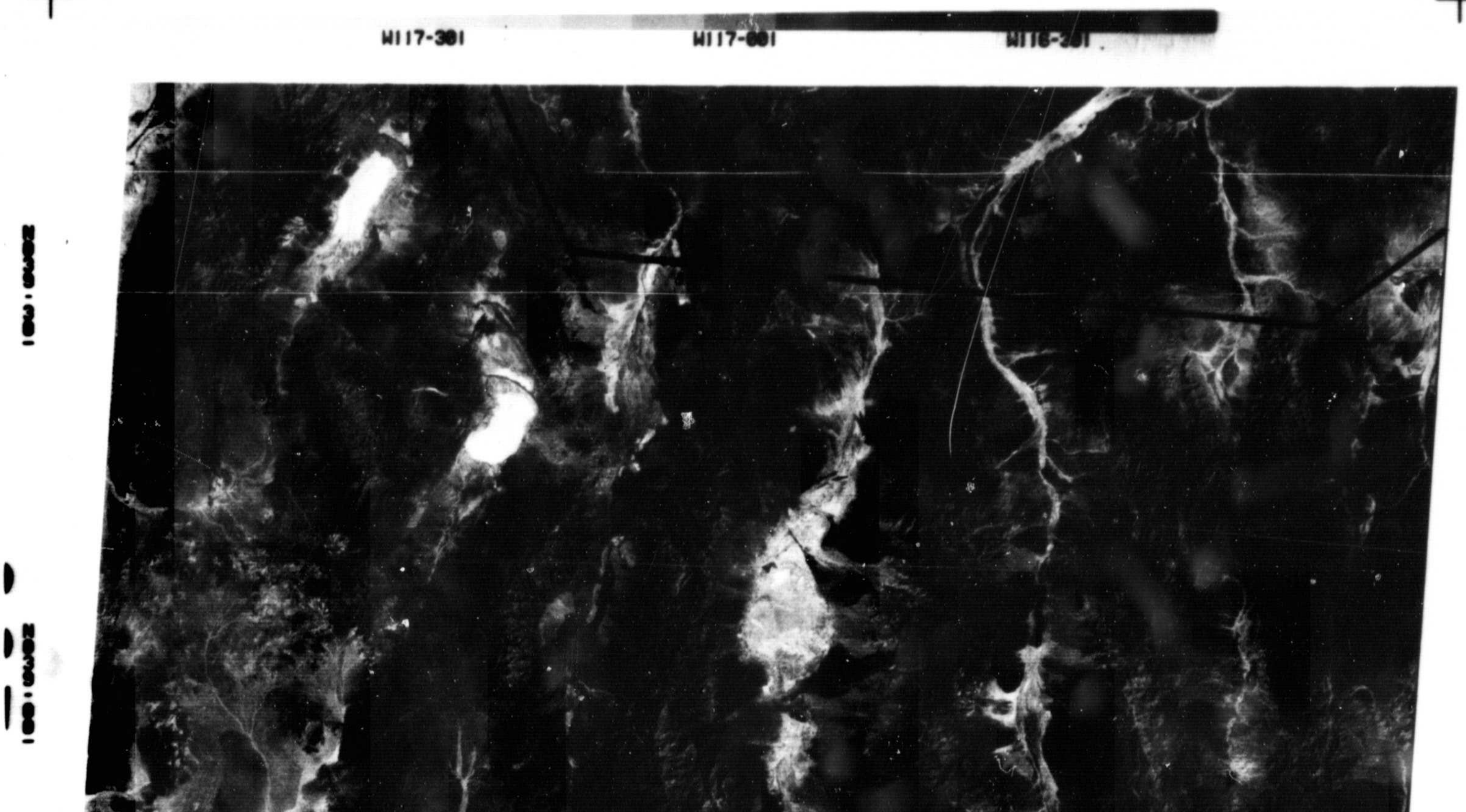
Battle Moutain-Eureka Special Study Area

Figure 41-A

0 20 40 60 80

miles


W117-00
W116-30
W116-00
W115-30
W117-30
W117-00
N039-30
W116-30
W116-00
03OCT72 C N40-20/W116-27 N N40-18/W116-21 MSS 7 D SUN EL40 AZ140 191-1004-G-1-N-D-1L NASA ERTS E-1072-17592-7 02


W117-30I
W117-00I
W116-30I
W118-00I
W117-30I
W117-00
23AUG73 C N38-52/W117-13 N N38-51/W117-04 MSS 7 D SUN EL52 AZ130


IW116-30
W116-001
W115-301
W115-001
N039-30I
N039-00I
W117-00I
N038-30I
C
1
2
3
B
W116-30I
W116-001
N038-001
IW115-30
12JUL74 C N38-53/W115-46 N N38-52/W115-36 MSS 7 D SUN EL59 AZ114 190-0026-G-1-N-D-1L NASA ERTS E-1719-17461-7 01

(Ely). By use of scale and rectification adjustments provided by the ZT-4, various recognizable linear cultural elements, e.g., roads, and railroads, as well as many topographic features could be placed in register with the map sheets. These functions permitted registration and facilitated comparison with other Landsat scenes.

Linear valley-stream/lineament segments within the study area were traced onto a transparent mylar overlay. The minimum segment length chosen was 1.6 km, the longest segment measured was approximately 25 km. After an interval of about 3 weeks, the imagery was re-registered to the map sheets and a new tracing of the stream and valley segments was made. The tracings were compared to test for the operator's repeatability in tracing the length and measuring the azimuths. Little variation was noted in the azimuth measurements; segment lengths varied as much as 1 km in about 10 percent of the measurements for the two trials. Lineaments within mining districts (the latter noted by dashed lines on Plate 5) were tallied together in order to have sufficient measuremnts to constitute a reliable sample.

Stream lengths were grouped into categories of 1.6-3.2 km (1-2 mi); 3.2-6.4 km (2-4 mi) and greater than 6.4 km (4 mi); and azimuths were grouped into class intervals of 30°. Because of the considerable variation in the total segments for each class, the data for the statistical test was selected for tally by use of a random number table.

2. Results

A Chi-square test was applied to each length category in order to determine if the number per azimuth class differed significantly between mineralized and non-mineralized areas. It was determined that within the 1.6-3.2 km group and the greater than 6.4 km length groups, there was no significant difference when alpha is set at 0.05 in either mineralized or non-mineralized areas. There was, however, a significant difference (with alpha set at 0.05) in the number per azimuth class in the northeast quadrant for the 3.2-6.4 km group when the mineralized and non-mineralized areas were compared.

Figure 42 illustrates the frequency percentage of valley-stream/ lineaments from Plate 5 of mineralized and non-mineralized areas as

PERCENT FREQUENCY LANDSAT LINEAMENTS FROM PLATE 5
RELATED TO AZIMUTH IN MINERALIZED
AND NON-MINERALIZED AREAS

CF TEXT p 94

M = MINERALIZED AREAS n = 189 NE QUADRANT = 81%

N = NON-MINERALIZED AREAS n = 344 NE QUADRANT = 84%

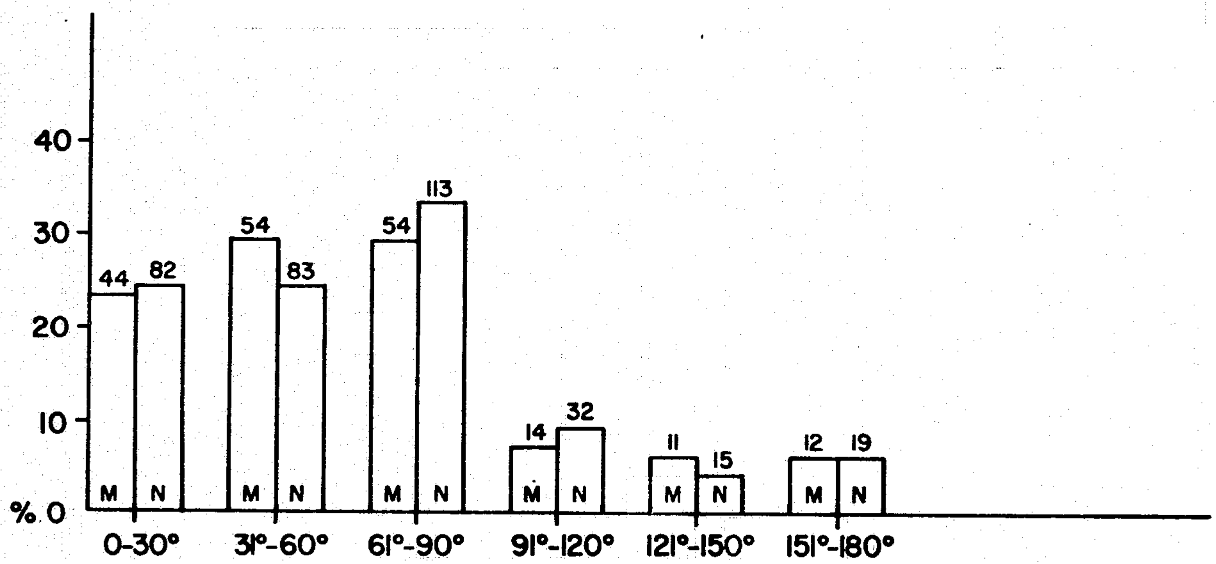


FIGURE 42

related to 30^{o} azimuth classes.

In both categories, it can be seen that the highest averaged percentage (83 percent) of the recorded azimuths occurs in the northeast quadrant. It is suggested that the illumination of Landsat scenes by a southeasterly sun producing northwest-directed shadows favors lineament definition with a northeast-southwest bias which has no necessary relation to structural trends.

3. Conclusions

Clustering of the 3.2-6.4 km group of valley-stream/lineaments in the northeast quadrant azimuth classes suggests that this length category in this direction may be useful for mineral exploration.

The slight preference shown in Figure 42 for the N 30^{o} - 60^{o} E direction in mineralized areas is in accordance with a study (Stokes, 1968) which confirmed a common field observation in western Utah that the trend of mineralized fractures appear to favor a northeasterly direction.

C. Valley-Stream/Lineament Length Related to Azimuth

Fig. 43 indicates the apparent relation of lineament length to azimuth in non-mineralized areas. Three categories of lineament length were established and discussed in part IV-2. These could be applied to mineralized and non-mineralized areas. An examination of lineaments on Plate 5 suggested that a fourth category, i.e. greater than 16 km (10 mi) could, in addition, be applied to non-mineralized areas. (Lineaments of this length do not appear to be associated with mineralized areas.) Incorporation of shorter lineament segments within this category becomes a matter of subjective judgement in the following circumstances:

1. Some segments interrupted by intermontaine valleys may be assumed to be continuous.
2. In some cases a lineament may be considered continuous even when segments display azimuth changes, if such segmentation, and rotation can reasonably be ascribed to tectonism.

A summation of percent frequency of lineament length from Figure 43 is as follows:

PERCENT FREQUENCY LENGTH OF LANDSAT LINEAMENTS FROM PLATE 5 RELATED TO AZIMUTH IN NON-MINERALIZED AREAS

CF TEXT p 96

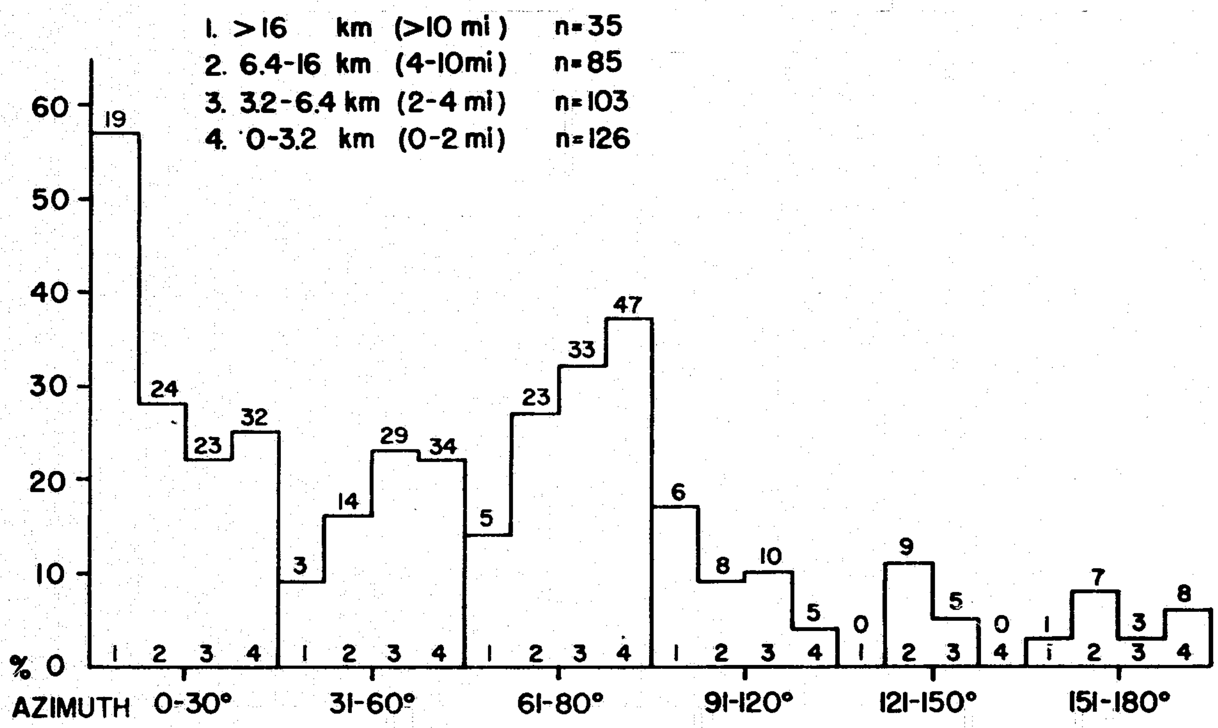


FIGURE 43

Category			Quadrant	
			$0 - 30^0$	$0 - 90^0$
1	16 km	(10 mi)	57%	80%
2	6.4-16	(4-10)	28	61
3	3.2-6.4	(2-4)	22	82
4	1.6-3.2	(0-2)	25	89

The strong preference for 16 km length lineaments in the $0\text{-}30^0$ azimuth class reflects range front and interior faults related to the development of Basin and Range (horst and graben ?) structures. The lesser percentage of 6.4-16 km length segments in the $0^0\text{-}90^0$ quadrant is noted. Reasons for this and a possible significance relative to mineral exploration are not clear.

The small percentage differences present among length within the southeast (northwest) quadrants (figure 43) appears to limit any diagnostic value.

D. Valley-Stream/Lineaments in Relation to Geology

The lineaments recognized at 1:250,000 scale occasionally corresponded with faults and geologic contacts on geologic maps of the same scale. Correspondence appeared to be more frequent in areas where bedding and faults have heightened tonal contrast. The most consistent correspondence of lineaments with faults mapped within ranges occurs parallel to range axes and within volcanic strata.

In summary, the valley-stream/lineaments noted in this portion of the study area do not, at the scale employed, accurately or consistently exhibit a definitive relation, viz. in density, azimuth continuity, or outline, to mapped structure or stratigraphic controls.

1. Recommendations

The possible relation between azimuth and valley-stream length to mineralization should be tested in other regions which are less structurally complex. The factor of lithologic variability was not adequately evaluated in this test and should be considered for its possible effect on stream segment length and azimuth.

In subsequent studies, and attempt should be made to test sample populations of more nearly equal size from mineralized and non-mineralized areas.

V. VALLEY-STREAM/LINEAMENT EXPRESSION AS RELATED TO DRAINAGE PATTERNS OF TOPOGRAPHIC MAPS

1. Introduction

As a second step in the examination of valley-stream length to azimuth, we investigated the relationship of these possible expressions of lineaments as recognized on Landsat, to the drainage system observed on topographic maps. Plate 6 is a tracing of all mountain drainage courses identified by stream symbols on the NK 11-11 (Winnemucca); NJ 11-2 (Millett) and NJ 3-11 (Ely) AMS sheets within the areas of interest. On this plate, adjacent parallel drainages were sometimes omitted for clarity in areas outside the outcrop boundary. The solid lines on Plate 6 represent limits of outcrop.

2. Drainages as Related to Topography

Valleys shown with stream symbols on the topographic map range in width from 1.25 km to 2.5 km (0.75 mi to 1.5 mi) as measured between outcrop limits.

Isolated ranges, circular in outline and dominated by a central peak, tend to exhibit radial drainage, A on Plate 6, (Antler Peak); B, (Fish Creek Mountains).

Linear ranges tend to develop a series of parallel drainages which generally trend normal to the range axes, C on Plate 6, (Shoshone Mountains). Tilted fault blocks (horsts?) with prominant dip slopes also exhibit parallel drainages which tend to be more closely spaced on the dip slope, D on Plate 6, (Cortez Mountains), and E, (Sulphur Springs Range).

Therefore, at the scale of the AMS sheets, stream valleys have channels whose trends appear directly related to the topographic form of the major structural elements in this area.

3. Drainages Related to Azimuth

Figure 44 shows the percent frequency of drainages in 30° azimuth classes measured from Plate 6 for mineralized and non-mineralized areas.

In contrast to the obvious preference for the northeast quadrant

PERCENT FREQUENCY DRAINAGE AZIMUTHS FROM PLATE 6

CF TEXT p 99

M = MINERALIZED AREAS n = 106
N = NON-MINERALIZED AREAS n = 385

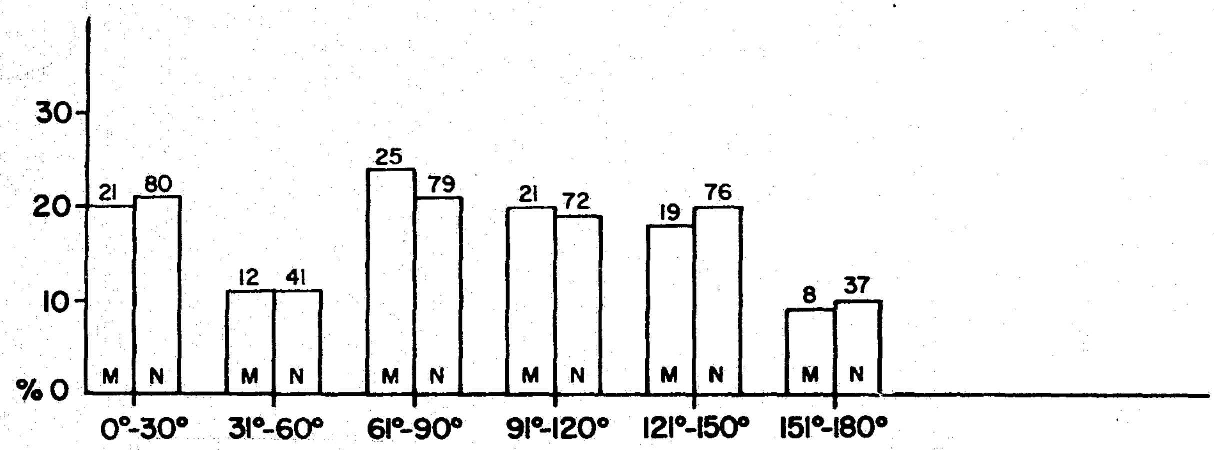


FIGURE 44

shown by lineaments (discussed in section IV), drainage azimuths show no preference for any quadrant. In mineralized areas, 55 percent of the drainages fall in the northeast quadrant while for non-mineralized areas, the figure is 53 percent. In the southeast quadrant, the figures are respectively 46 percent and 49 percent.

The percent decrease noted in the 31° - 60° and 151° - 180° classes is probably due to the fact that the direction of the axial crests of mountain ranges in this area trend between N 24° and 34° E.

A slight percent frequency decrease occurs in the 0-30° class. This decrease apparently reflects the affect of drainage counts taken from: circular ranges, drainages normal to east-west range front re-entrants, and irregular centrifugal pattern shown by drainages radiating from peaks within ranges.

In summary, at the AMS map scale, drainage channels designated by stream symbols do not appear to show any significant azimuth preference. The frequency of drainage azimuths is greatest in directions normal to the strike of axial crests of mountains ranges. The size of the channels annotated by symbols show they are major drainages and their courses are apparently adjusting and related to the major topographic elements. This appears in both mineralized and non-mineralized areas.

4. Drainage Length as Related to Azimuth

A study of the relation of stream azimuth to length was not undertaken due to the uncertainties involved in establishing a consistent, objective operational limit for stream length on the imagery.

5. Drainage Related to Geology

In isolated instances, drainages follow linear depressions that coincide with faults on the geologic maps. Lithologic boundaries, excepting an occasional portion of a margin of an extrusive igneous body, were not delineated by streams.

In summary, the drainage network depicted at the scale of the AMS maps appears to be too coarse to accurately or consistently exhibit a definitive relation (in density, azimuth, continuity, or outline) to structure or stratigraphic controls. Drainage patterns from topographic maps may however, be a useful adjunct to lineament mapping in the northwest

and southeast quadrants where lineament definition tends to be supressed.

There was no observed relationship by which these drainages would assist in the discrimination of mineralized from non-mineralized areas.

6. Valley-Stream/Lineament Expression Related to Topographic Contour Form

An attempt was made to relate the lineaments noted on Landsat to topographic form as expressed by contour lines shown on the AMS base maps. Several categories of contour patterns, figuratively illustrated in the form line drawing on Figure 45, appeared to be consistently related to alignments selected as possible lineaments. The patterns recognized can be grouped into the following categories:

a. Topographic lows occupied in any portion of a stream (as identified by stream symbol), Figure 45, 1.

Drainages shown on AMS map sheets may be permanent, intermittent, or dry. On the imagery they are commonly distinguished by channel development and/or lighter toned alluvial deposits. Tone and topography frequently combine to make this category generally recognizable at the scale of Landsat.

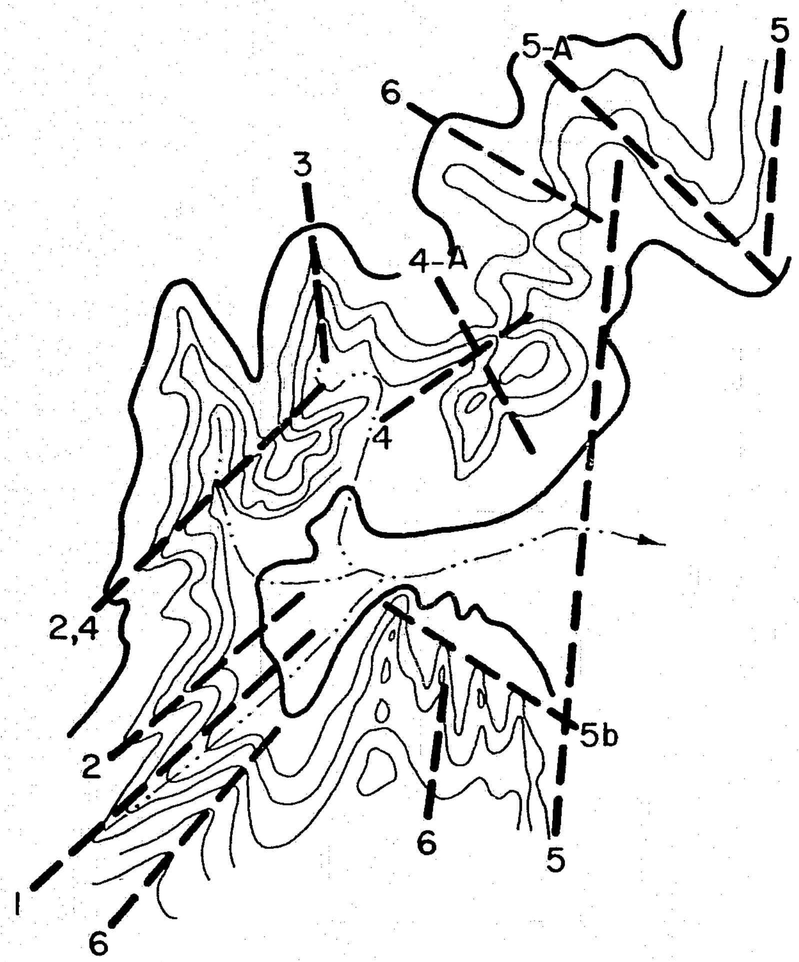
This category, as well as 2 and 3 (below), is delineated by the higher ground of one or both margins and is thus the converse of category 6 (Figure 45 and below). Thatis, a lineament originally recognized by the linearity of a stream channel (categories 1, 2) may be traceable over intervals by one or both of its accompanying parallel ridges.

b. Topographic depressions marginal to adjacent drainages, with or without stream symbol annotation, Figure 45, 2.

This category is identical to 1 in this area except for their generally smaller size. Shadow, outcrop form or pattern, ground cover, and sun angle may cause selective accentuation of these secondary drainages or depressions on some images.

c. Topographic depressions non-parallel to adjacent drainages, with or without stream annotation symbol, Figure 45, 3.

Linear depressions trending at some angle to regional topographic patterns may reflect the presence of a valid lineament. These may be expressed as forks occurring at a prominant angle to a major



TYPICAL EXAMPLES OF TOPOGRAPHIC CONTOUR FORMS
RECOGNIZED AS REPRESENTING LINEAMENTS
FIGURE 45

drainage. Of course, drainage forks per se are not indicative of a through-going regional structure.

d. Alignments of channel centerlines of opposite directed drainages separated by a ridge crest - identified when such alignments cross several parallel ridge crests, Figure 45, 4.

These alignments may parallel main drainages or range boundary faults. In such positions they appear to be related to faults sympathetic to the larger structures which control these features.

These apparent alignments often occur in trends perpendicular to each other, Figure 45, 4a.

e. Alignments parallel to range boundaries, Figure 45,5.

In the study area, range boundaries are in the main controlled by the northerly trending fault system of Cenozoic age responsible for the present configuration of the Basin and Range Physiographic Province. Categories 1, 2, and 3 above, when parallel to the range fronts, quite possibly are related to this rather recent episode of faulting. When these faults are offset by new or reactivated faults, local range front re-entrants are produced, Figure 45, 5a.

e-1. Alignments defined by the ends of parallel promontories, Figure 45, 5b.

An in-line or en-echelon termination of ridges may provide an apparent alignment which may be taken for a lineament extension. Isolated promontories along the ridge crests permit numerous choices for an apparent best fit for through-going lineament projections, many of which may be unrelated to regional structure.

f. Alignments marked by linear ridges, Figure 45, 6.

Linear ridges, especially when accentuated by adjacent colinear stream valleys and/or shadows, are often comspicuous on Landsat imagery and provide obvious guides for apparent lineament traces.

g. Cultural Anomalies, Figure 46. (p. 106)

Topographic maps were also used to identify such cultural elements as pipeline and power-line right-of-ways, unpaved rural roads, boundaries between cultivated and uncultivated fields, and fence lines, which sometimes were initially identified incorrectly as lineaments on the imagery.

Summary

Figure 46 is a tabulation of the percent frequency of lineaments noted within each topographic contour configuration comparing mineralized and non-mineralized areas. Because lineaments often are represented by more than one category, the percentage shown for each category may be expected to vary. In most cases, however, a lineament was distinguished on the imagery on the basis of a single category.

From Figure 46 it appears that categories 1 and 6 might afford some possibility for discrimination of mineralized from non-mineralized areas. Category 1, (streams), appear to be most often selected for lineaments in non-mineralized areas. Category 6, (ridge lines) appear to be most often chosen for lineaments in mineralized areas. As pointed out in section E-1, categories 1 and 6 are intrinsically complimentary. If the percentage frequency of categories 1 and 6 are combined, the mineralized equals 59 percent and the unmineralized is 64 percent. Thus the apparent diagnostic utility of these categories becomes negligible.

Category 4 accounts for 25 percent of the lineaments in mineralized districts. This may possibly reflect a greater intensity of fracturing, associated with mineral emplacement. Of course, many extensively fractured areas are unattended by mineralization. In this area, for example, 16 percent of the non-mineralized areas are in this category.

Based on the topographic contour configuration categories recognized in this study, there does not appear to be a form diagnostic for mineralized areas which can be consistently related to lineaments on Landsat imagery.

PERCENT FREQUENCY LANDSAT LINEAMENTS FROM PLATE 5
TOPOGRAPHIC CATEGORIES CF TEXT p 102

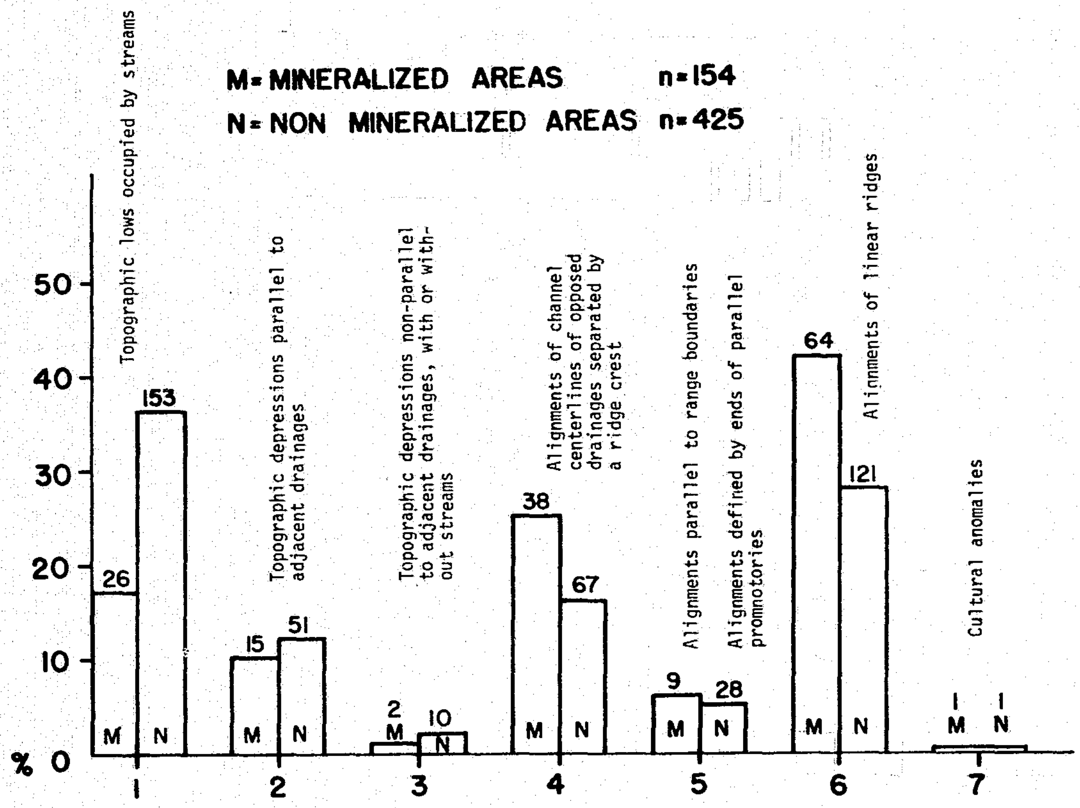


FIGURE 46

VI. RELATIONSHIP OF BASALTIC CONE AND FLOW ALIGNMENT TO MINING DISTRICTS

A. Introduction

During the examination of Landsat imagery centered at Lat. 41° 15' north, Long. 116° 15' west, on the northwest margin of the Fish Creek Mountains, a N 35° E alignment of isolated, conspicuously dark-toned and approximately circular outcrops were noted,(Plate 7 and image E-1846-17472, p 108.) Some of the outcrops surround dark circular or oval centers. Their shape, isolated occurrence and constructional landform appearance identified them as volcanic cones; their basaltic composition was confirmed from the geologic map of Lander County, Nevada.

It was noted that the center line azimuth of the basaltic cone alignment, when extended northward, passed through the acidic intrusives associated with the Copper Canyon and Copper Basin copper porphyry deposits of the Battle Mountain mining district.

We suggest here that cone and basalt flow alignments are a surface manifestation of fracture zones which extend into the crust to a depth sufficient to reach magma source areas capable of the production of such divergent rock types as basalt and granodiorite. Location of such fracture zones may provide a guide to the discovery of unknown acidic intrusives emplaced along the zone. Location of the intrusives is significant since the preponderance of mineral deposits invariably have a close spatial relation to intrusives.

Basalt is the most consistently recognizable lithology on the imagery within the study area. The location of acidic intrusives, and/or trends along which they may be emplaced, may thus be possible from the study of basalt outcrop trends visible on Landsat imagery. Where basaltic outcrops are masked continued surface expression of the alignments are sometimes manifested through the alignment of hot springs and their associated phenomena. Hot springs may at times be recognized on winter imagery as areas of perennial vegetation and/or as anomalous snow free or early melt areas in a snow-covered landscape.

The premise advanced that alignments of basalt cones and flows may be

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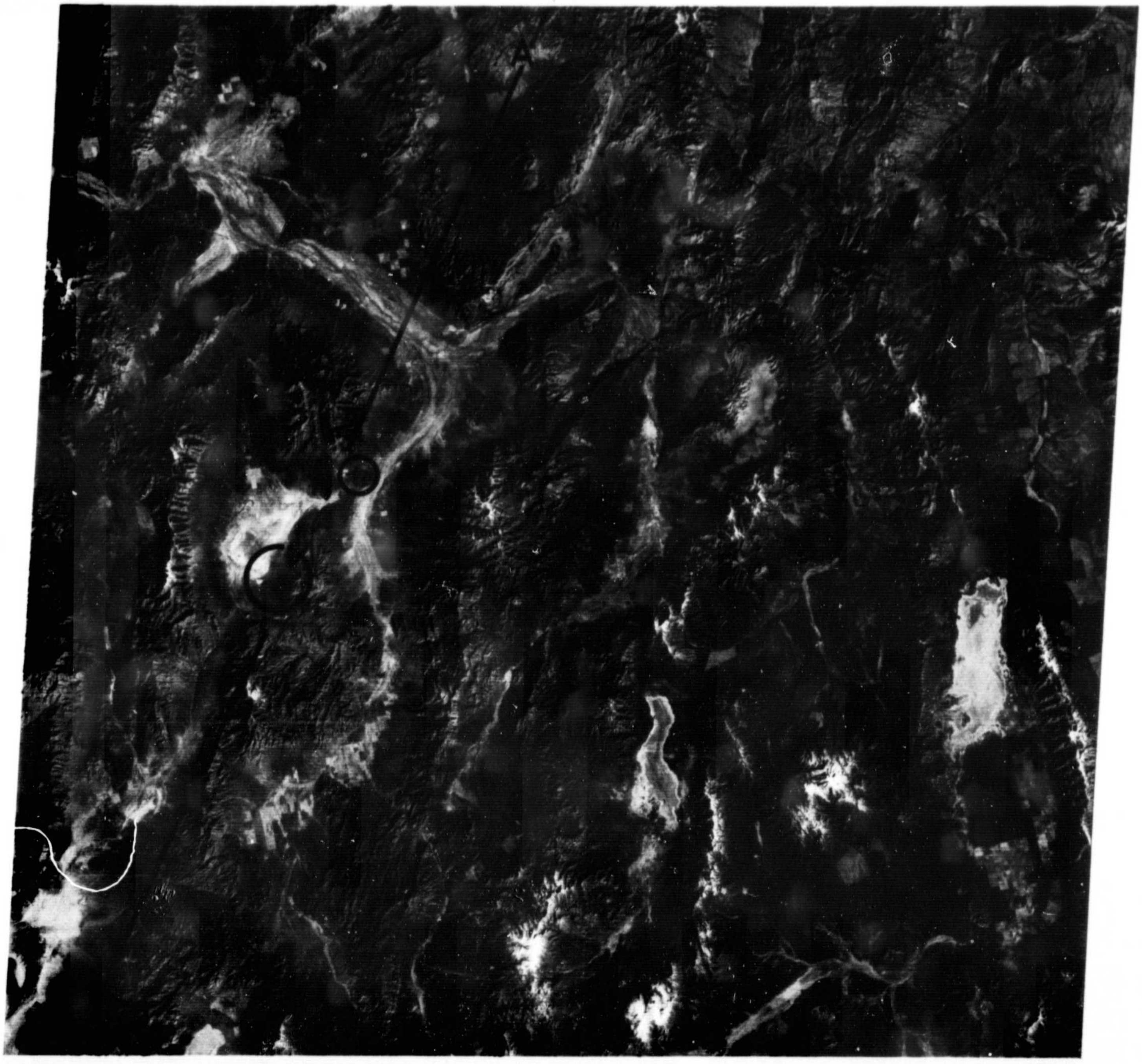


16NOV74 C N40-29/W116-42 N N40-10/W116-30 MSS 7 D SUN EL26 AZ152 191-1787-G-1-N-D-1L NASA ERTS E-1846-17472-7 01

indirect guides to mineral exploration is based on the following assumptions:

1. Chemically divergent magmas can utilize the same zones of crustal weakness for migration.
2. Epigenetic (post-depositional) accumulations of minerals within the study area are genetically related to igneous intrusions with silicic (quartz-rich) composition.
3. The minimum length of fissures associated with basalt cones and flows will necessarily be commensurate with depth estimates to the locus of the generation of basalt magmas, viz. 40-60 km (Yoder, 1976, p. 55).

On the basis of the above premise the trend of a basalt cone alignment just northwest of the Fish Creek Mountains (Plate 6, B), was extended on geologic and mineral resource maps from the Wonder Mining District, near the southern end of the Clan Alpine Mountains, to and beyond the northern edge of the study area. This trend, line A-A' Plate 11, (as shown on Landsat images E-1846-17472, p 108, E-1847-17530, p.110, E-2267-17525, p.111) was found to lie within 1.6 km (1 mi) of:

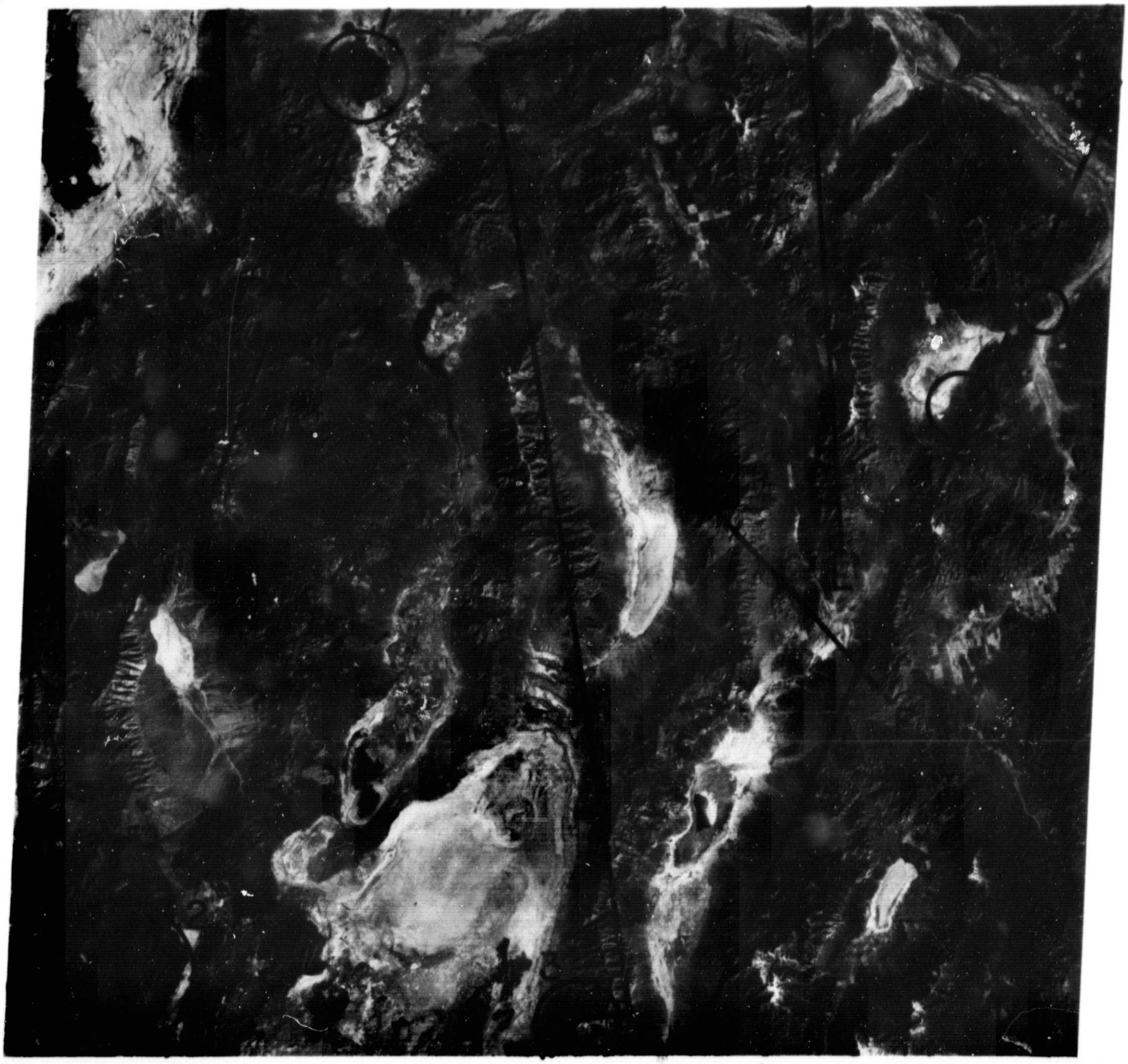
1. 4 mining districts:

		Value $1,000,000	Plate 1
a) Copper Canyon	(copper porphyry)	250*	#129
b) Copper Basin	(copper porphyry)	50*	129
c) Jersey	(Ag)	> 1#	102
d) Bernice	(Ag)	> 1#	107

* (Theodore, 1975)
\# (Mardirosian, 1974)

2. Silicic intrusives along the west face of the Clan Alpine Mountains: cf Plate 8.
3. Outcrops of basalt flows: cf Plate 7.
4. Numerous hot springs: cf Plate 7 or 8.

When the line is extended northward beyond the study area, it passes through or is adjacent to the northeasterly trending mining districts, intrusives, basalt flows, and hot springs located in northwestern Elko County. Extension of the trend southerly from the Clan Alpine Mountains is uncertain. It may terminate at the intersection with the northwestern



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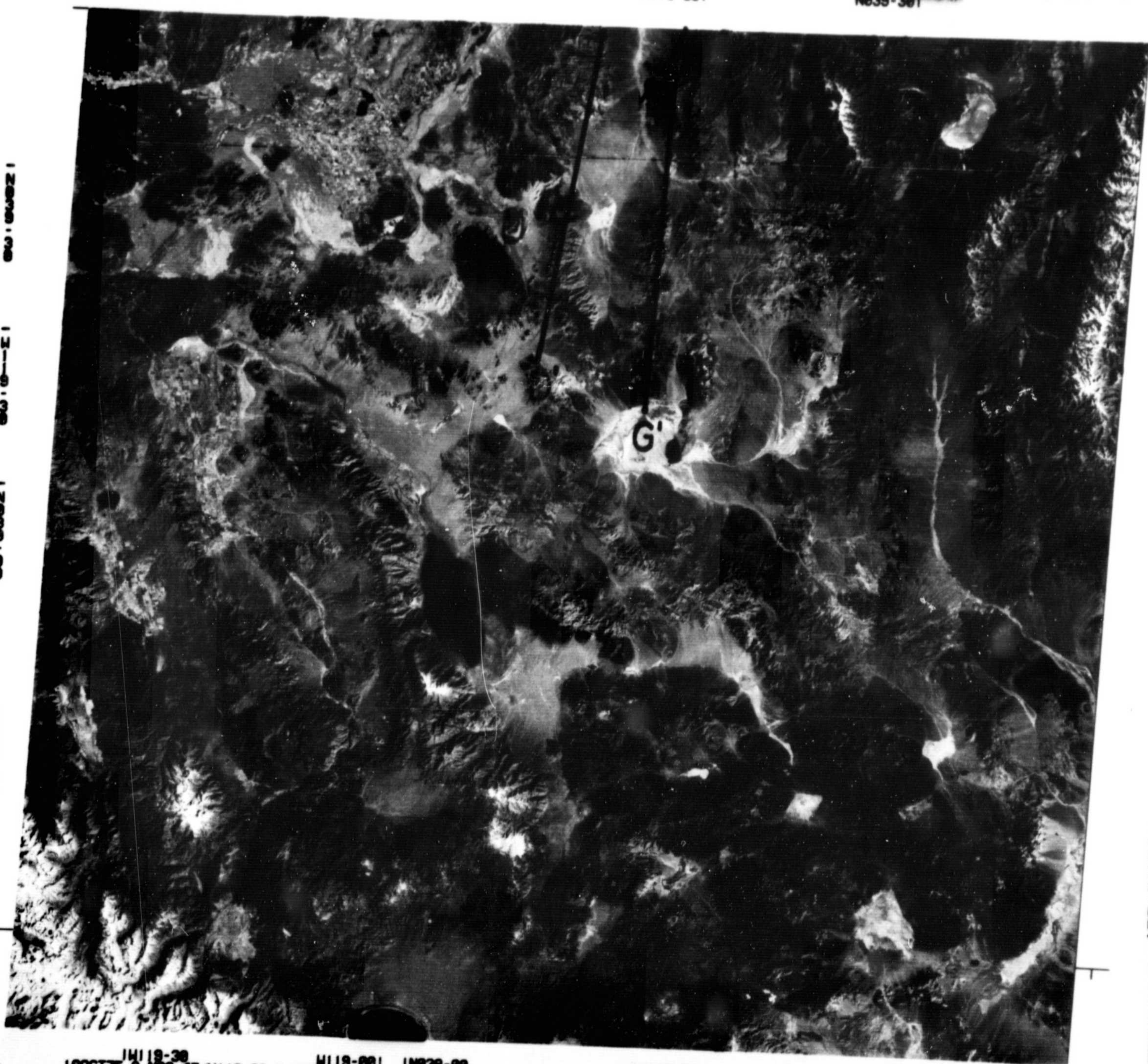

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trending complex of intrusives and basalt outpourings associated with the Walker Lane of Locke and Billingsley (1940). cf Plate 9. The length of this alignment is about 320 km (200 mi). It is also coincident with the northern end of the Wonder-Regent trend (cf p.135).

B. Definitions

1. Cones

a. Cinder cones are constructional landforms associated with an explosive stage of volcanic activity. Partially or wholly consolidated magma is explosively ejected as fragments which are of such size as to accumulate adjacent to the vent. The resultant conical-shaped accumulation generally is less than 300 m. in height. If the activity subsides gradually, the ejecta tends to be symmetrically arranged around the vent. This, together with inward slumping commonly results in a cone shape, the form often visible on Landsat imagery.

b. Spatter cones are developed when the ejected material is partly molten. The general shape is domical. Although distinctive in form, they have considerably less relief and are generally smaller than cinder cones. Normally their size will be below the resolution of Landsat but they contribute to the total bulk of a volcanic landform.

2. Ejecta Aprons

When the duration of the explosive event is short, and strong prevailing winds are present, the ejected material may fall to form a fan-shaped area downwind of the vent - an ejecta apron. Normally these will be co-located with cones or flows.

3. Volcanic Flows

Distinctive constructional landforms result when molten magma pours out onto the surface of the earth. The volcanic activity may range from a single event (monogenetic) to intermittently continuous (polygenetic). This can result in an accumulation of several thousand meters of overlapping flows. The source may be restricted to a single vent or a series

of vents along a linear fissure. The fissure length will be at least as long as the depth of the magma source. Volcanism involving basaltic lavas is relatively non-explosive; topographic slope as much as magma viscosity usually determines the shape and spatial distribution of this landform.

C. Recognition Elements

1. Shape

Cones and flows often were identified on Landsat imagery solely on the basis of their distinctive landforms.

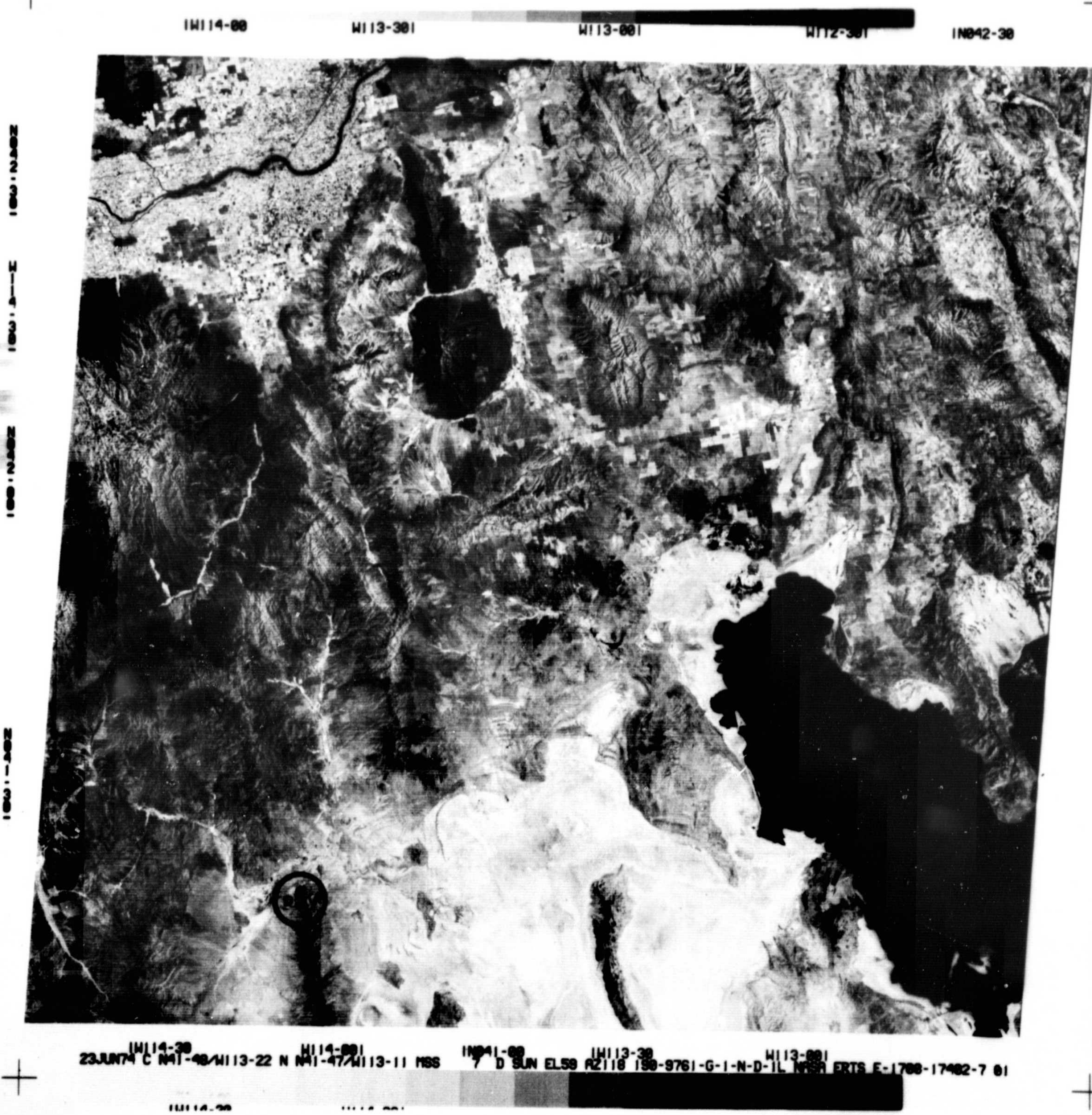
a. Cones - The conical shape can only be inferred from the imagery due to the vertical perspective and distance from the sensor to the land surface. The plan view, however, was often sufficiently distinctive to make identification. Cone rims may present continuous circular outlines, cf E-1846-17472, p. 108; more commonly they are incomplete, i.e., breached, and present an oval, "C" or "U" shape, cf E-1700-17402, p. 114 . Rim outlines are accentuated by the central depression, especially at lower sun angles and in some cases by snow cover. Because of variations in relief, diameter, and sun angle, the rim and central depression seen from a vertical perspective can vary in appearance from a black semi- or full circle to a shape resembling a raindrop imprint in soft mud. An isolated cone may be indistinguishable from a butte.

b.. Flows - The lobate margin of a flow affords the most characteristic and consistently identifiable geomorphic criterium. Sinuous bands which extend away from these margins result when flows follow surface drainages, cf E-1719-17461, (1), p. 93). Fan shapes, not unlike alluvial fans, were noted. These are formed when a flow of local extent spreads out from a point source on a slope. The general configuration of an extrusive boundary is generally curvilinear and may approach a circular shape, cf E-1719-17461 (2) p. 93 .

2. Tone

Cones and flows

The tone of basalt is generally conspicuously darker than the surrounding strata. There are, however, substantial areas of outcrop of dark-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toned rock in this area which, using the criterion of tone alone, would make them indistinguishable from basalt. Dark-toned volcanics common in the study area range from andesite (petrologicly transitional with basalt) to rhyolite (of granitic affinity). Sedimentary lithologies such as argillite and organic-rich carbonates also rival basalt in tone. In addition, such variables as weathering, alteration, vegetative and aeolian cover, discussed below, produce tonal modifications which are seasonally and/or band dependent.

3. Texture

   a. Cones - Due to the vertical perspective and the fact that the size of many of the cones noted approach the resolution capability of the MSS sensor, no definitive textural recognition criteria for cones on Landsat imagery were identified during this study.

   b. Flows - A dotted or mottled appearing pattern which in some texts is described as "snake or lizard skin" was observable on the surface of some flows. It is thought to result from mounds of lighter toned aeolian material (with and without vegetation) accumulated on the irregular surface of the flow, cf E-1267-17434, p. 116. This is best seen at magnifications equivalent to a 1:100,000 scale. Where comparisons were carried out with the larger scale U-2 imagery flown for this project, a distinctive surface "pitting" not unlike the vesicular texture present in some hand specimens was noted. These "pits" may be irregularities in-filled with light-toned (aeolian ?) material.

4. Pattern

   a. Cones - Due to a combination of scale, resolution, and cone size, but primarily because of the vertical perspecitve, no definitive surface pattern was observed to be associated with cones.

   b. Flows - "Fish scale": In areas where multiple flows have accumulated, a distinctive texture described here as "fish scale" may be observed, cf E-1847-17530, p. 110, (1). The "scales" are a series of broadly lobate, sub-parallel lines which appear to mark the limits of successive, incompletely overlapping flow margins. Post-depositional tilting, faulting, and erosion of the flows may play an important role in the development or accentuation of this feature.


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5. Size

a. Cones - Table 7 is a tabulation of dimensions of randomly selected cones; cones plus colluvium; and flows, as measured on 1:250,000 scale Landsat prints. A comparison with measurements of the same features taken from 1:250,000 geologic maps is included. As one example of geometric accuracy, the diameter of Lunar Crater, cf E-1719-17461, p. 93, (2), as taken from a 1:250,000 paper print (a third generation product) was measured as approximately 1000 km (3280 ft). In the literature, the diameter is given as 1.26 km (3800 ft), an apparent difference of 13 percent. In addition to such dimensional errors accumulated in the product prior to receipt by the investigator, (e.g. distortion from photographic and enlargement processes), the location accuracy of bedrock-alluvial interfaces is affected by the resolution limitation of Landsat. Additional errors may also be present as positional errors of the outcrop on the geologic basemap in use.

Details of cone clusters are limited by Landsat resolution capabilities to cones approximating 80 m in diameter. The minimum observed spacing between cones of this size was approximately 2 km. Accuracy in establishing the average azimuth for cone clusters is dependent on the trend length of the cluster. The original azimuth used to establish a regional trend (line A-A', Plate 7) was measured on the basis of a trend length of 15 km. The trend length for the Lunar Crater cluster is 32 km.

b. Flows - The lobate margins and irregular forms did not provide a suitable shape for meaningful measurements of linear dimensions.

6. Stratigraphic Criteria

The discrimination of basalts from other dark-toned, non-igneous rocks was somewhat facilitated by their juxtaposition with bedded sedimentary strata. This could be observed as an abrupt termination or interruption of bedded strata.

Cones and Flows - Isolated exposures in an alluvial valley or intermontaine basins, and at range margins, were conspicuous on the imagery, cf E-1052-17475, p. 119. Exposures occurring within mountain ranges were sometimes undetectable, even with the aid of geologic maps.

Abrupt changes in stream courses and encroachment of basalt onto

TABLE 7. DIMENSIONS (Km)

AREA	CONE LANDSAT	CONE & TALUS LANDSAT	CONE & TALUS MAP	FLOWS LANDSAT	FLOWS MAP
Utah:					
Black Butte	.75	.75 x 1.00	1.0 x 1.75	5.5 x 1.50	5.5 x 1.50
Baker Hills	.75	1.50 x 2.25	1.0 x 2.25	1.5 x 7.00	1.5 x 7.00
				5.5 x 6.25	4.5 x 7.00
Fish Springs	.75	2.25 x 3.50	1.75 x 3.25		
	.50*	2.12 x 3.50	2.00 x 4.00		
	.50*	1.00 x 5.00	1.12 x 4.75	27.5 x 12.5	28.75 x 6.25
Fumarole Butte				16.0 x 11.5	16.00 x 9.00
Nevada:					
Current Mtn. (White Pine Rge.)				37.0 x 21.25	22.50 x 36.0
Lunar Craters	1.00		1.26 (cone only)		
	.25	1.00 x 1.50	1.00 x 1.50		
	.25	3.00 x 2.25	2.00 x 1.50		
	.25	1.00 x 1.00	1.50 x 3.00		
				32.50 x 7.5	32.00 x 8.00
Fish Creek Mtn.	.50	1.20 x 1.5	1.00 x 2.0		
		2.00 x 1.75	1.25 x 1.5		
	.25	.50 x 1.25	.50 x 1.5		
				15.00 x 2.5	12.50 x 2.5
Truckee Rg.				25.50 x 41.75	25.50 x 42.0
Aurora Crater	1.50	13.75 x 10.0	14.50 x 15.0		

*Best Estimate


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lighter-toned alluvium provided more obvious evidence for flow limits.

D. Factors Affecting Recognition Elements

The factors influencing criteria can be grouped into physical processes which affect the outcrop and those technical factors which affect the imagery.

1. Weathering and Erosion

In addition to the elements of climate, mineral composition, and the degree of hydrothermal alteration, the proportion of fragmental material to lava plays an important role on the rate by which weathering and erosion modify recognition criteria.

a. Shape - A significant period of Tertiary basalt eruptions began about 43 m.y. ago and ended about 6 m.y. ago. Within this period basaltic outpourings included basalt, basaltic audesite and bimodal basalt and rhyolite, (Silberman, 1976). It was assumed that cones and flows would exhibit variations in weathering and erosion which could be related to this age range of emplacement.

In the Lunar Crater area of Nye County, Nevada, a study was made of cone and flow shape visible on the imagery using as control the conventional photography accompanying a U. S. Geological Survey report on the area (Scott and Trask, 1971). Personnel of the present project made low-level overflights of the area and later compared their observations and those of the Lunar Crater report with Landsat imagery. The variety of form in craters, cones and flows recorded during these observations were, for the most part, not visable at the scale and resolution of Landsat. Hindered by the lack of resolution of detail on the imagery it thus was not possible to develop reliable geomorphic criteria which would aid in age ranking basalt outcrops.

b. Tone - Tone may be considerably modified by agencies of weathering. Studies at Lunar Crater suggest the youngest outpourings exhibit the darkest tone (Scott and Trask, p. 13). It is probable that the decrease in the intensity of tone begins by masking from accumulations of aeolian material. Later, weathering, soil development and accumulation of vegetation are causes for the permanent loss of tone intensity.

c. Texture, pattern, size - In addition to the effect on tone, the development of soil profiles and the spread of cover are important in the development and alteration of texture, pattern, and ultimately in the leveling of the basalt outcrops. Initially, however, irregular vegetative patches or pockets of aeolian material (cf. sec. C 3 b, p. 115) assist in flow recognition.

2. Relief

a. Cone relief and shape greatly affect cone visibility. Low relief and irregular shape, developed initially or caused by subsequent erosion, may combine to blend a cone with surrounding topography. In the case of isolated older cones, the problem of recognition is aggravated by vegetative cover. Clusters of cones may assist recognition.

b. For flows, where the relief is low, aeolian deposits by themselves may eventually mask a flow, cf E-1861-17300, p. 122 , erosion or deposition at flow edges can modify or eliminate the characteristic lobate margins, cf E-1861-17300.

3. Image Quality

All 9" x 9" positive transparency imagery received during the course of this study was examined with the aid of a Bausch & Lomb binocular, variable power stereoscope at enlargements equivalent to a 1:100,000 scale. These were examined in pairs and compared band by band from the same scene and by comparing bands from scenes imaged in different seasons. In the latter situation a psuedo-stereoscopic effect was obtained which resulted in heightened relief. Subjective comparison of images was facilitated through an alternate masking of the microscope objectives while viewing different bands. Considerable variation in quality with regard to resolution and acutance was observed during scene to scene comparative studies.

Basalt on Landsat imagery appears to be the most consistently identifiable lithology, however, there are numerous factors which affect the rendition of the recognition elements on the imagery.

a. Technical parameters - Various technical deficiencies in data accession and image processing can result in images which comparatively


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are of poor quality. Such deficiencies are noted in an overall loss of resolution, contrast and acutance which tend to subdue tonal variations.

b. Atmospherics - Air moisture and aerosol content influence path radiance and contribute to non-uniform radiance values, an important variable affecting lithologic interpretation.

Irregularly distributed rainfall produces transient irregular tonal variations on surface rock.

Other factors include variations in reflectivity which became apparent as changing sun angle and azimuth interact with changes in slope angle.

c. Band evaluation - During the band by band study of the Special Study Area for evidence of basaltic outcrops, an informal, subjective evaluation of each band was developed. In general bands 7 and 5 appear to provide the best source of stratigraphic identification and comparison. Specifically, band 7 appears marginally the most useful.

E. Cone and/or Flow Alignments

Landsat imagery can be used to recognize and measure alignments of volcanic cones. The resulting data may then become the basis for recognizing preferred azimuths of possibly deep crustal fractures. In the study area, such fractures may also be related to alignments of acidic intrusives which appear, in some cases, to be colinear with alignments of mining districts

Cones associated with flows may be more difficult to locate due to (1.) lack of contrast against the flow and (2.) general scarcity.

Flows, unless they tend to be linear, generally do not present an obvious azimuth for determination of regional alignments. Flows of irregular dimensions, or with courses determined by surface drainage can provide erroneous azimuth information. Portions of the study area have a large number of basalt outcrops such that selection of practically any orientation for an underlying parent fracture appears possible. Undoubtedly some of these disconnected outcrops are continuous beneath the cover of Quaternary and Recent alluvium which also may mask their true axial direction.

The structural grain of an area may bias an observer. Within the

study area, some basalts do in fact appear to be related to the apparent regional structure grain. They appear to follows faults marginal to the mountain ranges, i.e., the Basin and Range fault system. This appears to be the case on line A-A', Plate 7. Other lines such as E-E' appear to follow Basin and Range faults over segments of their trend while intersecting the ranges at some angle along other segments. Still other lines, viz. B-B', C-C', G-G' (Plate 7) cross ranges with a variety of angles.

The width of the alignments of cones and flows is conjectural. At some locations adjacent to lines, there appear flow and intrusive outcrops whose axes are parallel to the trend. The apparent width of a few of these alignments are shown by double-headed arrows on Plate 7 and suggest a possible limit for the "zone of weakness" or "area of influence" of the parent fracture.

1. Clan Alpine Alignment Plate 7., A-A', Images E-1846-17472, p.108 ; E-1847-17530, p.110; E-2267-17525, p.111 .

As discussed in the introduction, alignment A-A' (Plate 7) was the first in which the strike of volcanic cones was recognized to be colinear with an alignment of mineral deposits, intrusions, basalt flows and hot springs. The dimensions of this line are shown on Table 7.

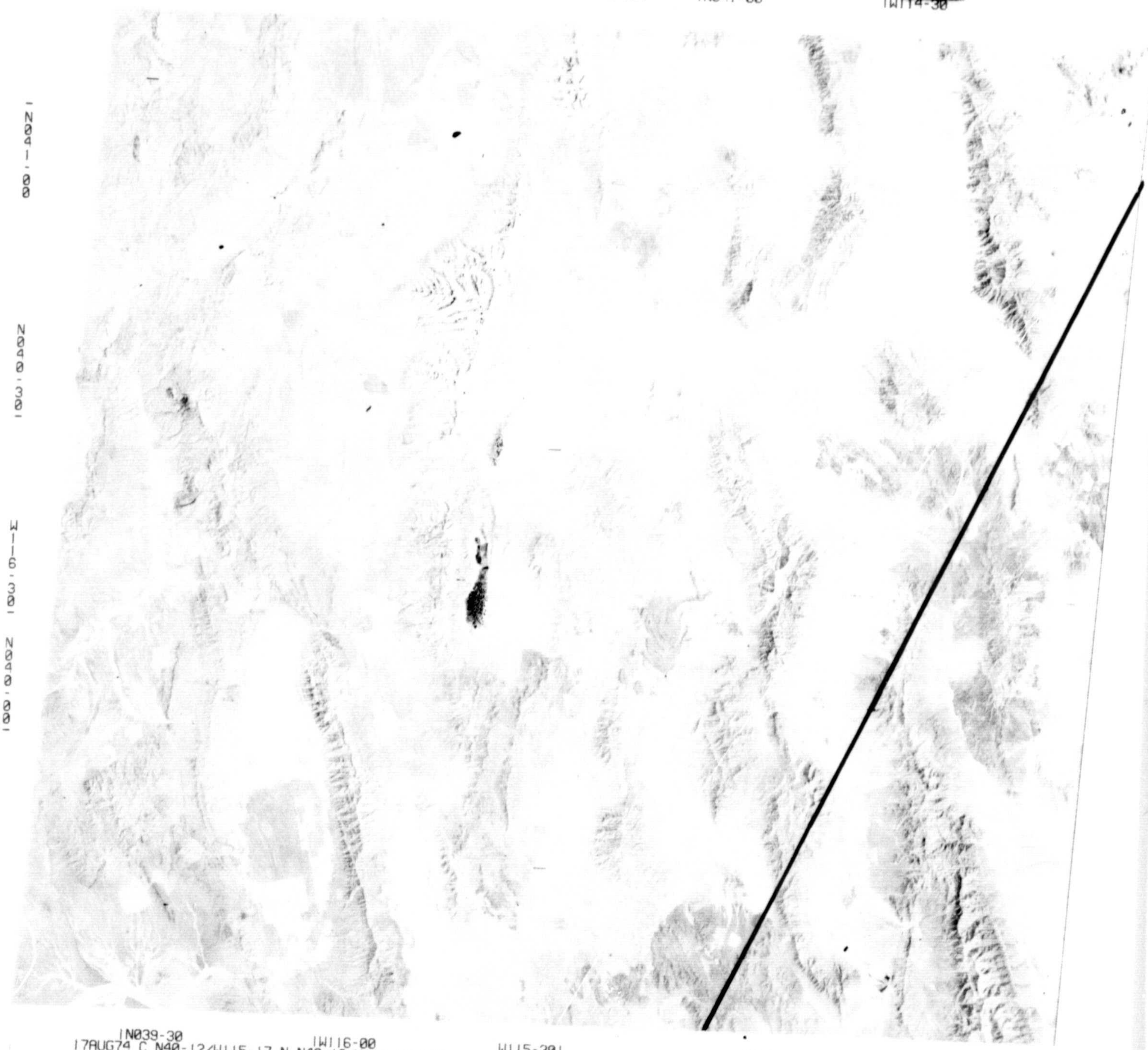
2. Lunar Crater Plate 7, B-B', Images E-1719-17461, p. 93; 1755-17443, p. 125; 1754-17385, p. 126; 1106-17481, p. 127.

Approximately 38 km south of the study area in Nye Country, Nevada is is the Lunar Crater volcanic field. Although the field lies outside the study boundary, it is of interest because of its documentation in the literature (Scott and Trask, 1971) and the parallelism of its N 30° E axial trend with the aforementioned A-A' trend 220 km to the west.

When this line was transferred to geologic and mineral resource maps, its trend was found to lie at the indicated distancefrom the following:

a. 12 mining districts:

		Value $1,000,000*	Plate 1
1) 13 km (10 mi)	Robinson (porphyry copper)	$1,000	#162
2) 22 km (12 mi)	Dolly Varden (porphyry copper)	0.1	176
3) 13 km (8 mi)	White Pine (Pb,Ag,Au,Cu,Zn)	29.6	143
4) 6.4 km (4 mi)	Hunter (Pb,Cu,Ag)	0.2	160
5) 3.2 km (2 mi)	Granite (Au,Ag,Pb)	0.2	161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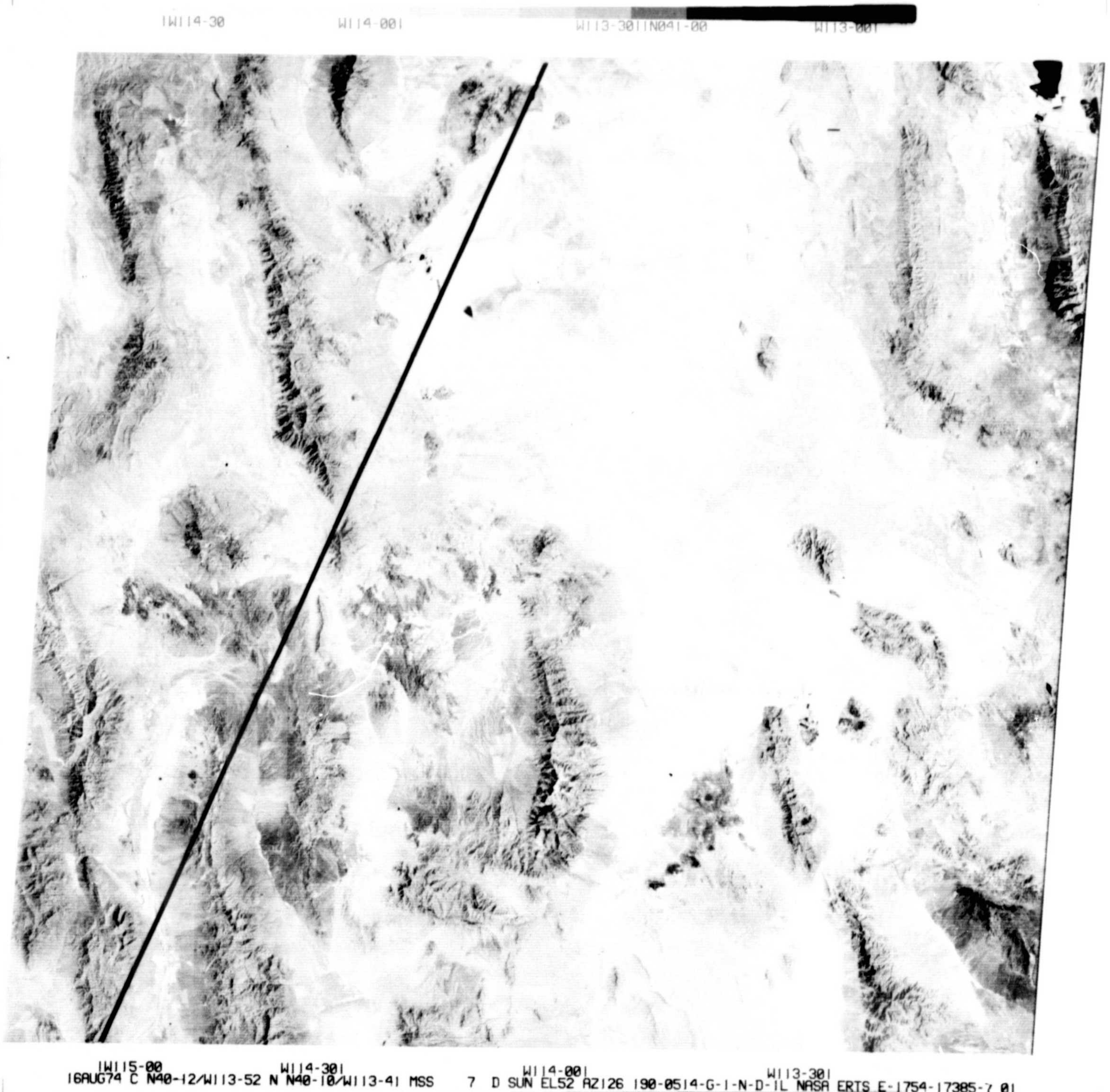

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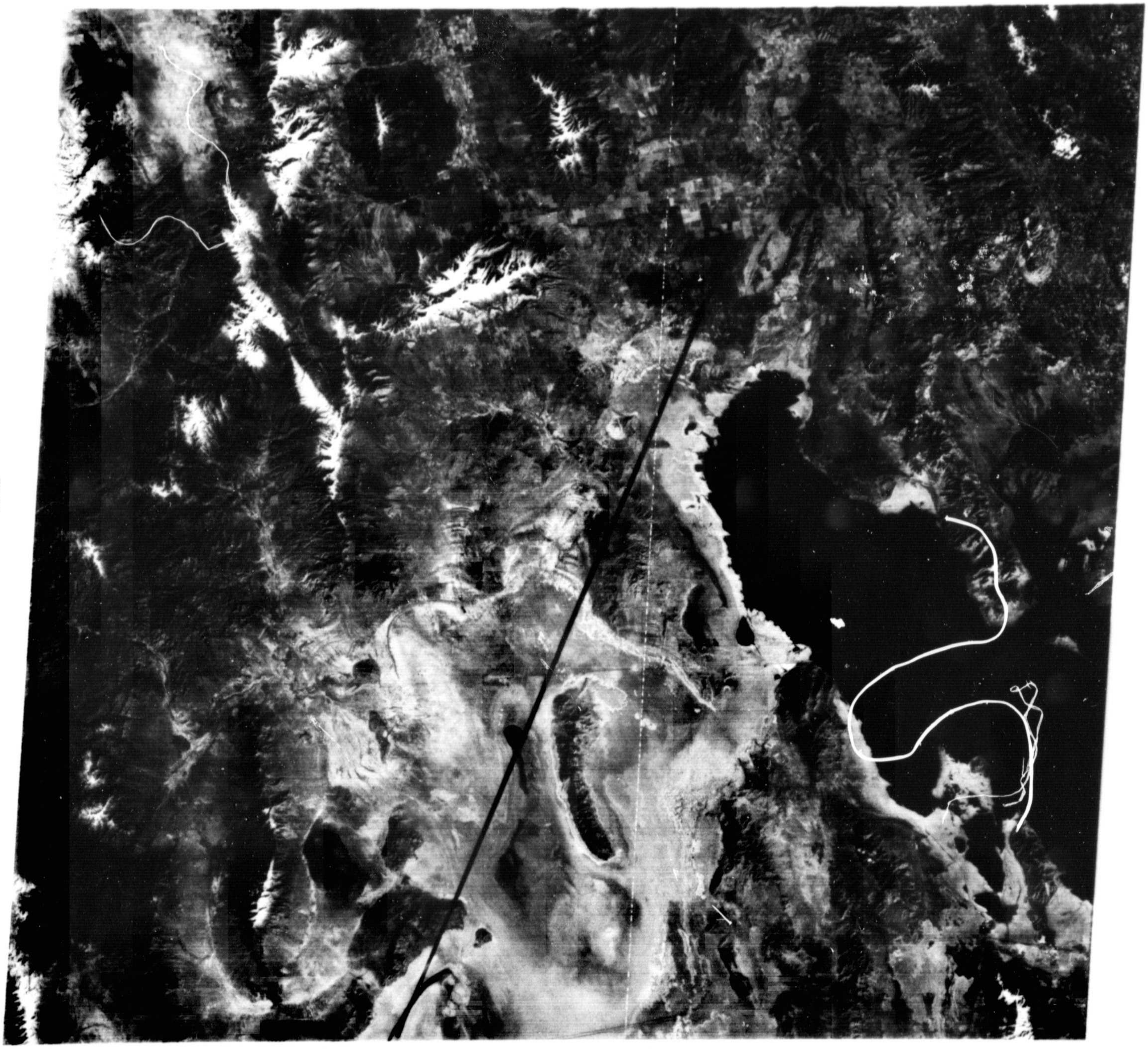

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6)	16 km (10 mi)	Cherry Creek (Wo,Au,Ag,Cu)	4.8	159
7)	8 km (5 mi)	Auram (Au,Pb,Cu,Ag)	1.1	187
8)	6.4 km (4 mi)	Kinsley (Cu,Pb,Ag,Au,Mo)	minor	180
9)	3.2 km (2 mi)	White Horse (Pb,Ag,Zn)	minor	178
10)	6.4 km (4 mi)	Ferguson Spring (Cu,Ag,Pb)	minor	177
11)	6.4 km (4 mi)	Silver Islet (Ag,Au,Cu,Zn)	> 0.1	172
12)	3.2 km (2 mi)	Newfoundland (Wo,Cu,Pb,Ag)	> 0.1	189

*Figures are from 1968

b. Silicic intrusives: cf Plate 8

intersects: 3
within 4.8 km (3 mi): 3
within 13 km (8 mi): 8

c. Intermediate extrusive centers: cf Plate 7

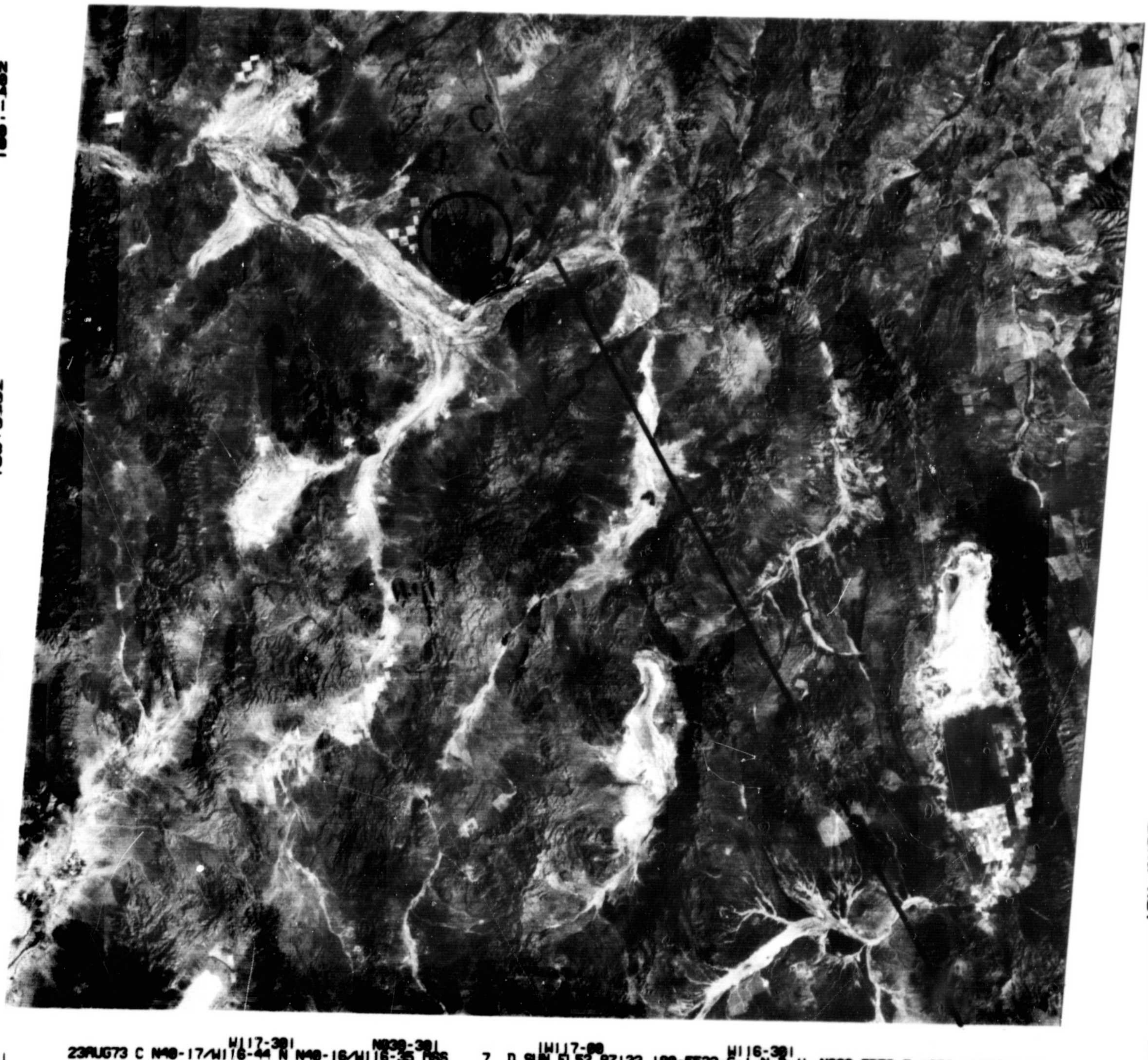
A trend passes to the west of (B-1, Plate 7) and through (B-2, Plate 7) E-1719-17461, p. 93 , two areas of older volcanic rocks which are described as originating from vent type eruptions (Hose and Blake, 1976, p. 18) and dated as Oligocene.

The northern terminus of this line is conjectural. If projected to the northern boundary of the study area, it falls approximately 4 miles east of two basalt cones with a connected center line strike of N 30°E. The distance along line B-B' (Plates 5, 6, 8), from Lunar Craters to these basalt cones is 460 km (290 mi).

3. Eureka-Battle Mountain Trend Plate 7, C-C', Images: 1719-17461 p. 93; 1396-17590, p. 129.

This trend was first recognized on the geologic map as an apparent alignment of basalt outcrops. Although discernible on the imagery, they could not be differentiated as basalt by visual methods. The trend extends N 20° W from the vicinity of Eureka, passing approximately 24 km (15 mi) east of Battle Mountain, Nevada.

The line is of additional interest in that a series of hot springs, designated by solid circles on Plate 7, is colinear with the basalt outcrop trend. One spring, C-1, Plate 7, is the Known Geothermal Source Area of Beowawe. On image E-1144-18001, p. 130 a winter scene, the steam plume is recognizable. The area of perennial vegetation is partly in shadow. It is also of interest that segments of this apparent lineament have been enhanced by snow cover.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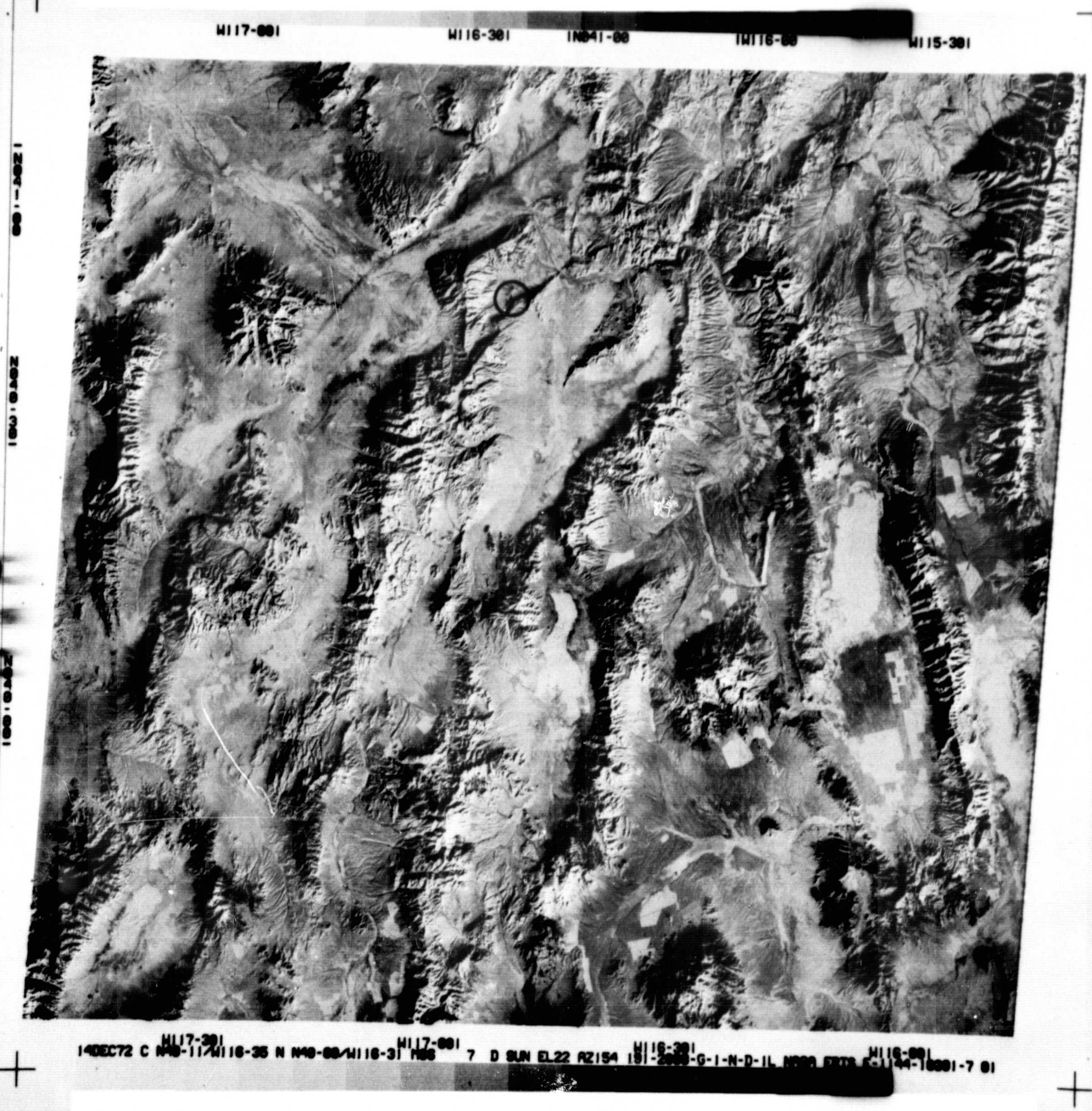
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The line, when transferred to geologic and mineral resource maps, lies at the indicated distance from the following:

a. 8 mining districts:

	Value $1,000,000*	Plate 1
1) 9.6 km (6 mi) Eureka (Pb,Au,Ag,Zn,Cu)	107.3	#141
2) 4.8 km (3 mi) Fish Creek (Pb,Au,Ag)	minor	142
3) 3.2 km (2 mi) Lone Mountain (Zn,Pb,Ag)	0.8	138
4) 8 km (5 mi) Mount Hope (Zn,Pb,Ag,Cu)	1.3	137
5) 1.6 km (1 mi) Antelope (Zn,Pb,Ag)	minor	136
6) 4.8 km (3 mi) Buckhorn (Au,Ag)	1.1	134
7) 11 km (7 mi) Cortez (Ag,Au,Pb,Cu)	3.7	239
8) 13 km (8 mi) Beowawe (Hg)	minor	146

*1938 Roberts and others

b. Silicic intrusives: cf Plate 8

intersects: 1

within 6.4 km (4 mi): 4

At C-2 (double arrow) Plate 8, the axis of the intrusive 6.4 km to the east is parallel to the basalt trend and suggests the possible lateral dimensions for the zone of fracturing.

The location of the northern terminus of this trend is conjectural. If extended beyond the hot spring adjacent to the project boundary, Plate 1, it would parallel an obvious lineament along the western margin of the Sheep Creek Range, cf E-1396-17590, p. 92 .

The location of the southern terminus is also conjectural. The southern-most linear basalt recognized along the trend is in the vicinity of Eureka.

An extension of this N 20° W trend to the southern boundary of the study area appears warranted based on small, discontinuous but linear basalt outcrops and N 15-20° W faulting shown on the geologic map. A hot spring is also present in this area, Plate 7, C-3 & Plate 10.

4. McDermitt-Sand Springs trend, Plate 7, D-D', Images: E-1847-17524, p. 132; 1847-17530, p. 110; E-2267-17525, p. 111.

This apparent alignment of cones and basalt outcrops trends N 10° E. It was also noted as a lineament in another section of this report prior to the initiation of the basalt studies. Numerous basalt outcrops are recognizable on Landsat imagery.

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Proceeding southerly from McDermitt, Nevada, the alignment of highly visible basalt outcrops extend south along the eastern margin of the Santa Rosa Range. In the vicinity of Winnemucca, D-1, Plate 7, there appears to be a right lateral translation of about 26 km. Here the outcrops lack the dark tone generally associated with basalt. However, the "fish scale" pattern described in section V-C-4b, p. 115, here becomes an important recognition element.

Basalt outcrops at the north end of the succeeding segment can be seen on the imagery, but lack the normal dark tone. Their small size precludes pattern recognition. At present, this portion of the alignment has been defined only on the geologic map.

In the junction where the line intersects the Stillwater Range, a mixed group of silicic intrusives and basalts show up on the imagery of E-1847-17530, p. 110 (3), as a series of linear outcrops. Another apparent right lateral shift of 6.4 km is indicated here, D-2, Plate 7.

Further south well displayed examples of "fish scale" pattern indicate the location of basalt outcrops and the continuation of this line. As with line A-A' the presumed southern terminus of this line is against the Walker Lane.

The length of the projected line within the study area is 344 km (215 mi). When transferred to the mineral resource map, the alignment is found to lie at the indicated distances from:

a. 18 mining districts

			Plate 1	Value $1,000,000
1)	3.2 km (2 mi)	Buckskin (Au,Ag,Hg)	-*	> 0.1
2)	3.2 km (2 mi)	Shon (Au,Ag,Wo)	-	minor
3)	0 km	Winnemucca (Ag,Au,Pb,Cu)	-	< 0.1
	0	Ten Mile (Ag,Au,Pb,Cu)	-	minor
4)	3.2 km (2 mi)	Star (Sb,Ag,Pb)	#242	-
5)	6.4 km (4 mi)	Imlay (Au,Ag,Hg)	60	< 1
6)	9.6 km (6 mi)	Rye Patch (Ag,Au,Wo)	61	< 10
7)	3.2 km (2 mi)	Unionville (Ag,Au,Pb,Cu)	62	< 10
8)	3.2 km (2 mi)	Indian (Ag,Au)	63	< 1
9)	8.0 km (5 mi)	Sacramento (Ag,Au,Pb)	64	< 1
10)	3.2 km (2 mi)	Spring Valley (Au,Ag,Pb)	68	< 10
11)	3.2 km (2 mi)	Rochester (Ag,Au)	69	< 10
12)	1.6 km (1 mi)	Antelope Springs (Hg,Sb)	70	< 10
13)	3.2 km (2 mi)	Copper Kettle (Cu)	74	< 1
14)	6.4 km (4 mi)	White Cloud (Cu,Au,Ag)	75	< 1
15)	1.6 km (1 mi)	Shady Run (Au,Ag)	76	< 1
16)	1.6 km (1 mi)	I.X.L. (Ag,Au,Pb,Zn)	77	< 1

17) 1.6 km (1 mi) Mountain Wells (Ag)	78	<	1
18) 1.6 km (1 mi) Sand Springs (Ag,Au)	50	<	10

*out of area

b. Silicic intrusives: cf Plate 8

intersects: 5

within 6.4 km (4 mi): 14

In summary, although there are basalt outcrops visible on Landsat their continuity is open to interpretation. Examination of the outcrop pattern shown on the geologic map was the primary source of data for establishing the trend of this line.

5. Hot Springs - Tobin Range, Plate 7, E-E', Images: E-1847-17524, p. 132; 1847-17530, p. 110.

This apparent trend is as yet recognized only on the geologic map. It is included here as an example where substantial areas of basalt are mapped, but have minimal observed signature on Landsat imagery.

The line has a North-South trend and approximately follows the axis of the Hot Springs and Tobin mountain ranges.

On the geologic and mineral resource maps, its trend at the indicated distance to the following:

a. mining districts

	Value $1,000,000	Plate 1
1) 1.6 km (1 mi) Big Mike (Cu)	< 10	#96
2) 6.4 km (4 mi) Aldrich (Ag,Pb,Sb,Wo)	< 1	97
3) 9.6 km (8 mi) Gold Banks (Hg,Au,Ag)	< 1	99
4) 0 0 Mount Tobin (Hg)	< 1	101

b. Silicic intrusives: cf Plate 8

intersects: 4

within 3.2 km (2 mi): 8

c. Basalt outcrops: cf Plate 7

d. Hot springs: cf Plates 7, 8, 10

The apparent northern terminus of this line is at the north end of the Hot Springs Range, E, Plate 7, Basalt occurs on the east flank of this range and on the west flank of the Osgood Mountains which lie immediately to the east, E-1, Plate 7, E-1847-17524, p.132 (1). The

southern terminus of the line is arbitrarily placed in the vicinty of basalt and andesite outcrops at the south end of the Tobin Range.

The length of trend line E-E', as recognized, is 70 km (44 mi).

In summary, an apparent trend of basalt outcrops colinear with mining districts shown on the geologic map does not show up on Landsat imagery. The reason for the lack of a recognizable basalt signature is not known. Field work will be required to evaluate the validity of this trend and adequately relate its significance to Landsat imagery.

6. Augusta Mountains-Granite Mountains, Plate 7, F-F', Images E-1847-17530 p. 110.

This apparent trend was recognized from the geologic map. It extends from dark toned (andesite) flows on the southwest pediment of the Augusta Mountains, (F) Plate 7, N 35^{o} W to basalt outcrops southeast of Granite Mountain (F'). The latter exhibits a typical "fish-scale" pattern.

On the mineral resource map, it lies at the indicated distance to the following:

a. from 1 mining district

	Value $1,000,000	Plate 1
0 km (0 mi) Kennedy (Au,Ag,Cu,Pb)	> 1	#100

b. silicic intrusives: cf Plate 8

intersects: 1

c. basalt and/or andesite outcrops: cf Plate 7

d. hot springs: cf Plate 10

This apparent basalt alignment is similar to C-C' in that it trends at a substantial angle to the Basin and Range fault system. Its alignment is postulated largely on the basis of the apparent linearity of hot springs, arrangement of basalt outcrops and near linearity with trend C-C'

7. Wonder - Regent (Rawhide), Plate 7, G-G', Image: E-2267-17525, p. 111.

The name of this trend is identified with the names of mining districts located near each end, cf Plate 1; Table 1. The trend was originally recognized on the imagery from the alignment of light toned intrusives and/or their alteration zones.

The northern terminus coincides with the southern terminus of trend A-A', the Clan-Alpine alignment, p. 124. From this point the trend of G-G' diverges southerly to approximately N 20° E. The southern terminus is arbitrarily placed at the locus of a Cretaceous granite, cf Plate 8. The length of this trend is 56 km (35 mi).

On the geological and mineral resource maps the trend lies at the indicated distance to the following:

a. 4 mining districts

		Value $1,000,000	Plate 1
1) 1.6 km (1 mi)	Wonder (Ag,Au)	6.3*	#79
2) 0 km	Chalk Mountain (Pb,Ag,Au)	0.1*	80
3) 0 km	Fairview (Ag,Au,Pb,Cu)	4.4*	82
4) 0 km	Regent (Rawhide)(Au,Ag,Sb)	1.5#	53

*Wilden, R, 1974
#Ross, D., 1961

b. silicic intrusives: cf Plate 8

intersects:	5
within 1 km (0.6 mi)	2

c. basalt and intermediate intrusives: cf Plate 7

Basalt dikes are reported in the literature (Wilden, 1974, p. 88) in the vicinity of Wonder. These are not resolved on the image. The extrusives visable on the image are sufficiently separated that they tend to substantiate rather than identify this trend.

In summary, the trend located on imagery by identification of light toned acidic intrusives in association with dark toned extrusives suggests that imagery examined for this combination may prove a useful adjunct to regional mineral exploration techniques.

VII. RELATIONSHIP OF CONE AND FLOW ALIGNMENTS TO INTRUSIONS

Examination of Plate 9 which shows trends A-A' to G-G' discussed in the text also indicates the location of basalt and acidic intrusive outcrops used to establish these trends. The geometric arrangement of the basalts range from an elongate cluster, as at the southern end of A-A' and central area of D-D', to an irregular scattering along the length of a trend, G-G' and C-C'. The uneven outcrop distribution required an interpolation of the trends for variable distances.

Locally basalt outcrops are co-located with acidic intrusives as at the southern end of A-A' and E-E' and inthe central area of D-D' and C-C'. The presence of an iron-magnesium rich basalt juxtaposed with a silica-rich granodiorite or granite, coupled with the apparent trend of basalt outcrops provides the rationale for the premise that these trends define a regional framework of fracture systems which contain and channel migration of magmas.

The possible extent of this system is suggested by the discontinuous grid system drawn on Plate 10. A parallelism of axial trends of acidic outcrops suggest a possible lateral dimension for the trends (cf double-headed arrows, Plate 7, 8. A grid system parallel to the major trends, may be drawn where they can be shown to connect several intrusions. The location of known intrusions occasionally occur at grid line intersections.

As the spacing and/or projections of a grid system is established, a network of additional intersections can be plotted and used as an exploration guide for "blind" intrusive - and potential mineral - centers.

1. Summary

Basalt appears to be the most consistently identifiable rock type on Landsat images within the area studied. Criteria useful for its identification on an image include: darkest or relatively darker tone; shape (cone and lobate margin); surface (pattern and texture); and relationship to surroundings.

Basalt outcrops occur as isolated exposures predominantly in the form of cones and flows. Some cones are noted to be aligned in clusters

and some flows appear to have axial alignments. It is suggested these alignments follow and define regional fracture systems.

At some locations basalts are shown on the geologic map to be co-located with acidic intrusives, e.g. granodiorites and granites. Significantly, it is these silica-rich rock types that often are associated with mineralization. A current view regarding the locus of magma generation requires that such fractures extend to near the base of the crust in order to tap the magma source. Age dates from intrusions along the alignments indicate emplacement as early as 150 m.y. b.p. If this apparent physical and temporal continuity can be established for fractures associated with mineral emplacement, it would significantly simplify mineral exploration by minimizing the masking effects of repeated tectonism and weathering.

2. Recommendations

Considerable time has been spent on the visual examination of imagery in efforts to locate and recognize basalt outcrops. Band ratioing and density slicing techniques should now be applied in an effort to improve basalt discrimination.

Regional gravity and magnetic data should be compared to the imagery to assist in location and orientation of basalts. These results should be integrated with a field and laboratory examination to establish the following:

1. location and orientation of basalts in mineral districts,
2. variations in the composition of basalts associated with mineralization as compared to non-mineralized intrusives,
3. the relation of regional fracture patterns to basalts,
4. that causes affect the imaging of basalts on Landsat.

The anticipated result of this work would be the recognition of parameters which would, 1) define the basalt trends associated with mineral deposits, and 2) develop a regional grid pattern of actual or projected fracture azimuths similar to those discussed above. The resulting definitions and intersections could be an important aid in directing geophysical and geological metallic mineral exploration programs.

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APPENDIX A

Remote sensing of geologic mineral occurrences on a regional basis using Landsat data

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MINING DISTRICTS WITHIN UTAH-NEVADA STUDY AREA

TABLE TO ACCOMPANY MINING DISTRICT AND MINERAL OCCURRENCE OVERLAY

PROJECT NUMBER REFERENCE	MINING DISTRICTS OF NEVADA	COUNTY	AMS SHEET
1	STATELINE PEAK	WASHOE	RENO
2	PEAVINE	WASHOE	RENO
3	GALENA	WASHOE	RENO
4	LITTLE VALLEY	WASHOE	RENO
5	VOLTAIRE	ORMSBY	RENO
6	GENOA	DOUGLAS	RENO
7	STEAMBOAT SPRINGS	WASHOE	RENO
8	JUMBO	WASHOE	RENO
9	DELAWARE DISTRICT	ORMSBY	RENO
10	GARDNERVILLE	DOUGLAS	WALKER LAKE
11	MOUNTAIN HOUSE	DOUGLAS	WALKER LAKE
12	RISUE CANYON	DOUGLAS	WALKER LAKE
13	PYRAMID	WASHOE	RENO
14	WEDEKIND	WASHOE	RENO
15	CASTLE PEAK	STOREY	RENO
*16	COMSTOCK	STOREY	RENO
*17	SILVER CITY	LYON	RENO
18	COMO	LYON	RENO
19	BUCKSKIN	LYON	RENO
20	MOUNT SIEGAL	DOUGLAS	WALKER LAKE
21	RED CANYON	DOUGLAS	WALKER LAKE
22	WELLINGTON	DOUGLAS	WALKER LAKE
23	WELLINGTON	LYON	WALKER LAKE
24	WILSON	LYON	WALKER LAKE
25	WASHINGTON	LYON	WALKER LAKE

* CRIB FORM
__ PRODUCTION > $1,000,000

PROJECT NO.	MINING DISTRICTS OF NEVADA	COUNTY	AMS SHEET
*26	AUROA	MINERAL	WALKER LAKE
27	OLINGHOUSE	WASHOE	RENO
28	RED MOUNTAIN	LYON	RENO
29	RAMSEY	LYON	RENO
*30	TALAPOOSA	LYON	RENO
31	CHURCHILL	LYON	RENO
*32	YERINGTON	LYON	WALKER LAKE
33	MOUNTAIN VIEW	MINERAL	WALKER LAKE
34	BUCKELY	MINERAL	WALKER LAKE
35	MOUNT GRANT	MINERAL	WALKER LAKE
*36	HAWTHORNE	MINERAL	WALKER LAKE
37	NIGHTINGALE	CHURCHILL	RENO
38	JUNIPER RANGE	CHURCHILL	RENO
39	FIREBALL	CHURCHILL	RENO
40	TRUKEE	CHURCHILL	RENO
41	JESSUP	CHURCHILL	RENO
42	DESERT	CHURCHILL	RENO
43	BENWAY	LYON	RENO
44	HOLY CROSS	CHURCHILL	RENO
45	BULLION	MINERAL	RENO
46	VELVET	PERSHING	LOVELOCK
47	RAGGED TOP	W. PERSHING	LOVELOCK
48	LAKE	CHURCHILL	RENO
49	FOURMILE FLAT	CHURCHILL	RENO
50	SAND SPRINGS	CHURCHILL	RENO
*51	REGENT (RAWHIDE)	MINERAL	RENO
52	LEONARD	MINERAL	RENO

PROJECT NO.	MINING DISTRICTS OF NEVADA	COUNTY	AMS SHEET
53	EAGLEVILLE	MINERAL	RENO
54	BOVARD	MINERAL	WALKER LAKE
55	FITTING	MINERAL	WALKER LAKE
56	IRON CROWN	MINERAL	WALKER LAKE
*57	GARFIELD	MINERAL	WALKER LAKE
58	IRON GATE	MINERAL	WALKER LAKE
*59	SANTA FE	MINERAL	WALKER LAKE
60	IMLAY	PERSHING	LOVELOCK
*61	RYE PATCH	PERSHING	LOVELOCK
*62	UNIONVILLE	PERSHING	LOVELOCK
63	INDIAN	PERSHING	LOVELOCK
64	SACRAMENTO	PERSHING	LOVELOCK
65	WILLARD	PERSHING	LOVELOCK
66	ARABIA	PERSHING	LOVELOCK
67	BLACK KNOB	PERSHING	LOVELOCK
68	SPRING VALLEY	PERSHING	LOVELOCK
*69	ROCHESTER	PERSHING	LOVELOCK
*70	ANTELOPE SPRINGS	PERSHING	LOVELOCK
71	MUTTLE BERRY	PERSHING	LOVELOCK
72	WILD HORSE	PERSHING	LOVELOCK
73	BUENA VISTA HILL	PERSHING	LOVELOCK
74	COPPER KETTLE	CHURCHILL	RENO
75	WHITE CLOUD	CHURCHILL	RENO
76	SHADY RUN	CHURCHILL	RENO
77	I.X.L.	CHURCHILL	RENO
78	MOUNTAIN WELLS	CHURCHILL	RENO
*79	WONDER	CHURCHILL	RENO

PROJECT NO.	MINING DISTRICTS OF NEVADA	COUNTY	AMS SHEET
80	CHALK MOUNTAIN	CHURCHILL	RENO
81	WESTGATE	CHURCHILL	RENO
*82	FAIRVIEW	CHURCHILL	RENO
83	EAST GATE	CHURCHILL	MILLETT
84	GOLD BASIN	LANDER	MILLETT
85	BRUNER	NYE	MILLETT
86	ELLSWORTH	NYE	TONOPAH
87	BROKEN HILLS	MINERAL	RENO
*88	LODI	NYE	TONOPAH
*89	MAMMOTH	NYE	TONOPAH
90	PARADISE PEAK	NYE	TONOPAH
91	FINGER ROCK	NYE	TONOPAH
92	FAIRPLAY	NYE	TONOPAH
93	ATHENS	NYE	TONOPAH
94	BELL	MINERAL	TONOPAH
95	BLACK DIABLO	PERSHING	WINNEMUCCA
96	BIG MIKE	PERSHING	WINNEMUCCA
97	ALDRICH	PERSHING	WINNEMUCCA
98	POLLARD CANYON	PERSHING	WINNEMUCCA
99	GOLD BANKS	PERSHING	WINNEMUCCA
100	KENNEDY	PERSHING	WINNEMUCCA
101	MOUNT TOBIN	PERSHING	WINNEMUCCA
102	JERSEY	PERSHING	WINNEMUCCA
103	BLACK EAGLE	LANDER	WINNEMUCCA
104	McCOY	LANDER	WINNEMUCCA
105	ROMAN	PERSHING	WINNEMUCCA
106	TABLE MOUNTAIN	PERSHING	MILLETT

PROJECT NO.	MINING DISTRICTS OF NEVADA	COUNTY	AMS SHEET
107	BERNICE	PERSHING	MILLETT
108	WILD HORSE	LANDER	MILLETT
109	TUNGSTEN MOUNTAIN	PERSHING	MILLETT
110	ALPINE	PERSHING	MILLETT
111	NEW PASS	LANDER	MILLETT
112	RAVENSWOOD	LANDER	MILLETT
113	SPOOKUM	LANDER	MILLETT
*114	REESE RIVER	LANDER	MILLETT
115	BIRCH CREEK	LANDER	MILLETT
116	SPENCER HOT SPRING	LANDER	MILLETT
117	KINGSTON	LANDER	MILLETT
118	WASHINGTON	NYE	MILLETT
119	JACKSON	LANDER	MILLETT
*120	UNION	NYE	TONOPAH
121	TWIN RIVER	NYE	TONOPAH
122	JETT	NYE	TONOPAH
123	HORSE CANYON	NYE	TONOPAH
124	CLOVERDALE	NYE	TONOPAH
*125	ROUND MOUNTAIN	NYE	TONOPAH
126	GOLD HILL	NYE	TONOPAH
*127	NORTHUMBERLAND	NYE	TONOPAH
128	BUFFALO VALLEY	HUMBOLDT	WINNEMUCCA
*129	BATTLE MOUNTAIN	LANDER	WINNEMUCCA
*130	LEWIS	LANDER	WINNEMUCCA
131	HILL TOP	LANDER	WINNEMUCCA
132	BULLION (GOLD ACRES)	LANDER	WINNEMUCCA
133	BLACK BIRD	LANDER	WINNEMUCCA

PROJECT NO.	MINING DISTRICTS OF NEVADA	COUNTY	AMS SHEET
134	BUCKHORN	EUREKA	WINNEMUCCA
135	ROBERTS	EUREKA	MILLETT
136	ANTELOPE	EUREKA	MILLETT
137	MOUNT HOPE	EUREKA	MILLETT
138	LONE MOUNTAIN	EUREKA	MILLETT
139	DIAMOND	EUREKA	ELY
140	NEWARK	WHITE PINE	ELY
*141	EUREKA	EUREKA	ELY
142	FISH CREEK	EUREKA	MILLETT
*143	WHITE PINE	WHITE PINE	ELY
*144	LYNN	EUREKA	WINNEMUCCA
145	MAGGIE CREEK	EUREKA	WINNEMUCCA
146	BEOWAWE	EUREKA	WINNEMUCCA
147	SAFFORD	EUREKA	WINNEMUCCA
*148	RAILROAD	ELKO	WINNEMUCCA
149	MODARELLI (FE)	EUREKA	WINNEMUCCA
*150	MINERAL HILL	EUREKA	WINNEMUCCA
151	UNION	EUREKA	WINNEMUCCA
152	ALPHA	EUREKA	WINNEMUCCA
153	BALD MOUNTAIN	WHITE PINE	ELY
154	LEE	ELKO	ELKO
155	RUBY VALLEY	ELKO	ELKO
156	VALLEY VIEW	ELKO	ELKO
157	MUD SPRINGS	ELKO	ELKO
158	DELKER	ELKO	ELKO
159	CHERRY CREEK	WHITE PINE	ELY
160	HUNTER	WHITE PINE	ELY

PROJECT NO.	MINING DISTRICTS OF NEVADA	COUNTY	AMS SHEET
161	GRANITE	WHITE PINE	ELY
*162	ELY	WHITE PINE	ELY
163	DUCK CREEK	WHITE PINE	ELY
164	NEVADA	WHITE PINE	ELY
165	LAFAYETTE	ELKO	ELKO
166	WARM CREEK	ELKO	ELKO
*167	SPRUCE MOUNTAIN	ELKO	ELKO
168	LUCIN	ELKO	WELLS
169	LORAY	ELKO	WELLS
173	PROCTOR	ELKO	ELKO
174	DARKEY	ELKO	ELKO
175	DECOY	ELKO	ELKO
*176	DOLLY VARDEN	ELKO	ELKO
177	FERGUSON SPRINGS	ELKO	ELKO
178	WHITE HORSE	ELKO	ELKO
179	FERBER	ELKO	ELKO
180	KONGSLEY	ELKO	ELKO
185	TUNGSTONIA	ELKO	ELY
186	RED HILLS	ELKO	ELY
187	AURUM	ELKO	ELY
*188	PIERMONT	ELKO	ELY
238	DANVILLE	NYE	TONOPAH
*239	CORTEZ	LANDER	WINNEMUCCA
242	STAR	PERSHING	LOVELOCK

PROJECT NO.	MINING DISTEICTS OF UTAH	COUNTY	AMS SHEET
168	LUCIN	BOX ELDER	BRIGHAM CITY
170	PARKDALE	BOX ELDER	BRIGHAM CITY
171	CRATER	BOX ELDER	BRIGHAM CITY
172	SILVER ISLET	TOOELE	TOOELE
181	DRY CANYON	TOOELE	TOOELE
182	PROBERT	TOOELE	DELTA
183	TROUT CREEK	JUAB	DELTA
184	SPRING CREEK	JUAB	DELTA
189	NEW FOUNDLAND	BOX ELDER	BRIGHAM CITY
190	LAKESIDE	TOOELE	TOOELE
192	FREE COINAGE	TOOELE	TOOELE
193	THIRD TERM	TOOELE	TOOELE
194	GRANITE MOUNTAIN	TOOELE	TOOELE
195	DUGWAY	TOOELE	TOOELE
*196	FISH SPRINGS	JUAB	DELTA
*197	DETROIT	JUAB	DELTA
198	CRATER HOT SPRINGS	JUAB	DELTA
200	DESERT TUNGSTEN	JUAB	DELTA
201	WEST TINTIC	JUAB	DELTA
202	BLUE BELL	TOOELE	DELTA
203	IRON KING	TOOELE	TOOELE
204	COLUMBIA	TOOELE	TOOELE
205	ERICKSON	TOOELE	DELTA
206	LAKEVIEW	RICH	OGDEN
207	BOX ELDER	BOX ELDER	BRIGHAM CITY
208	HYRUM	CACHE	OGDEN
209	MINERAL POINT	CACHE	OGDEN

PROJECT NO.	MINING DISTRICTS OF UTAH	COUNTY	AMS SHEET
210	WILLARD	BOX ELDER	OGDEN
211	WEBER	WEBER	OGDEN
212	PROMONOTORY	BOX ELDER	BRIGHAM CITY
213	FREMONT ISLAND	WEBER	BRIGHAM CITY
214	ARGENTA	MORGAN	OGDEN
215	MORGAN	MORGAN	OGDEN
216	FARMINGTON	DAVIS	SALT LAKE
217	HARDSCRABBLE	MORGAN	SALT LAKE
218	HOT SPRINGS	SALT LAKE	SALT LAKE
*219	STOCKTON	TOOELE	TOOELE
*220	WEST MOUNTAIN	SALT LAKE	TOOELE
*221	OPHIR	TOOELE	TOOELE
*222	CAMP FLOYD	TOOELE	TOOELE
*223	NORTH TINTIC	TOOELE	TOOELE
*224	TINTIC (EUREKA)	JUAB	DELTA
225	TROTTER	UTAH	PRICE
226	MOUNT NEBO	JUAB	PRICE
227	SANTAQUIN	UTAH	PRICE
228	PAYSON	UTAH	SALT LAKE
229	SPANISH FORK	UTAH	SALT LAKE
230	PROVO	UTAH	SALT LAKE
231	WILD CAT	UTAH	SALT LAKE
232	ALPINE	UTAH	SALT LAKE
*233	AMERICAN FORK	UTAH	SALT LAKE
*234	BIG & LITTLE COTTONWOOD	SALT LAKE	SALT LAKE
*235	PARK CITY	SUMMIT	SALT LAKE
236	BEAVER CREEK	SUMMIT	SALT LAKE

PROJECT NO.	MINING DISTRICTS OF UTAH	COUNTY	AMS SHEET
237	FERRY	WASATCH	SALT LAKE
240	SIERRA MADRE	BOX ELDER	BRIGHAM CITY
*241	<u>GOLD HILL</u>	TOOELE	TOOELE

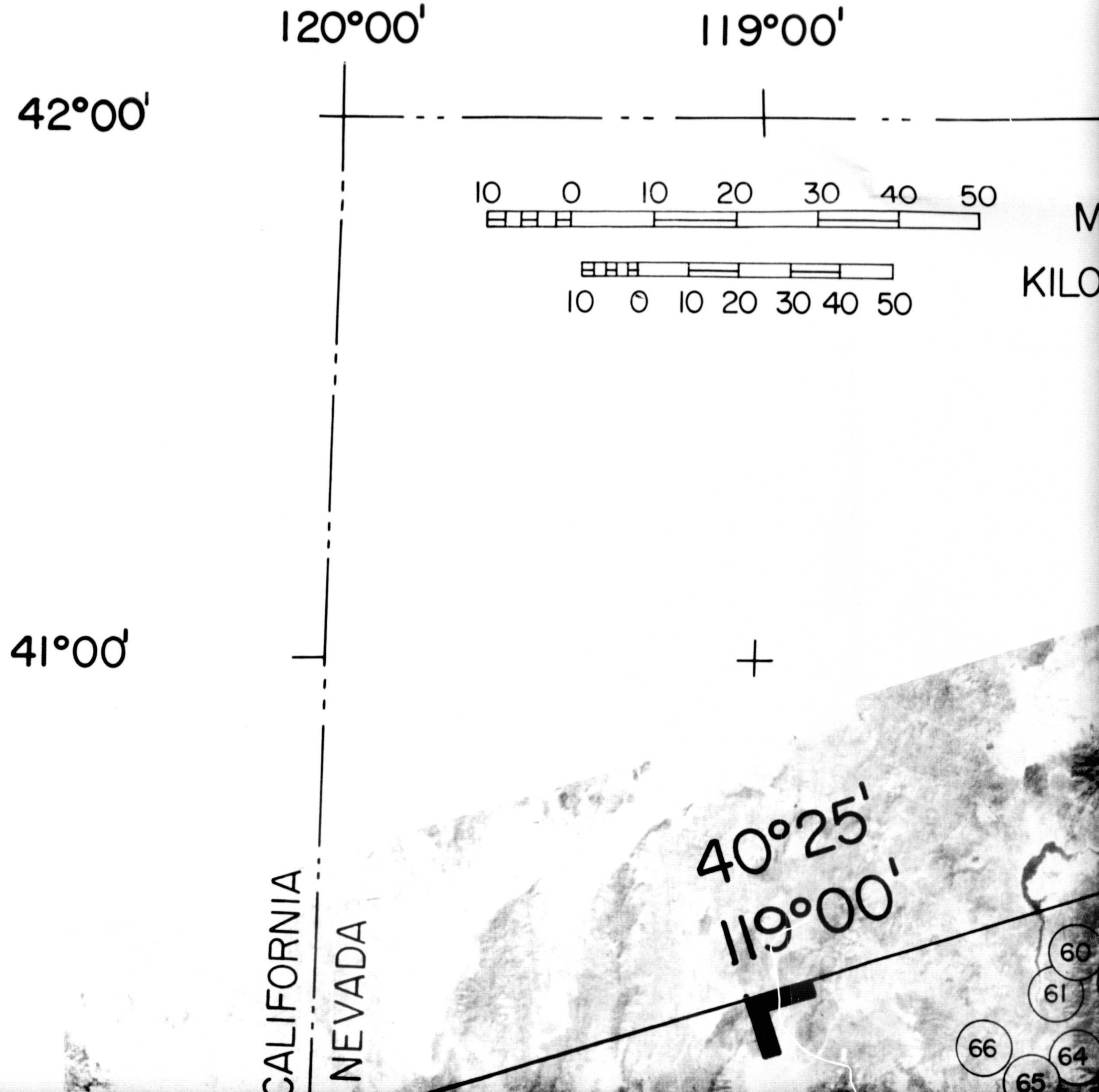
Appendix B

List of Landsat Frames used in Utah-Nevada study area:

1:250,000 Prints	1:500,000 Prints
E-1051-17423-5	E-1014-17361-5
1052-17475-7	1052-17472-7
1144-18001-7	1052-17475-5
1392-17361-5	1052-17481-7
1397-18051-5	1071-17531-7
1753-17331-5	1071-17533-7
1754-17383-5	1071-17540-7
1754-17385-5	1072-17592-5
1754-17392-5	1092-18111-7
1755-17441-5	1092-18114-7
1755-17443-5	1375-17420-7
1755-17450-5	1396-17583-5
1771-17323-5	1396-17592-5
1774-17493-5	1397-18051-5
1788-17262-5	1411-17410-7
1792-17482-5	1448-17455-7
1792-17491-5	1465-17404-7
1807-17305-5	
1812-17593-5	
1812-18002-5	
2268-17581-5	
1755-17545-5	
1755-17554-5	
1793-17543-5	

BASE AND PRECIO

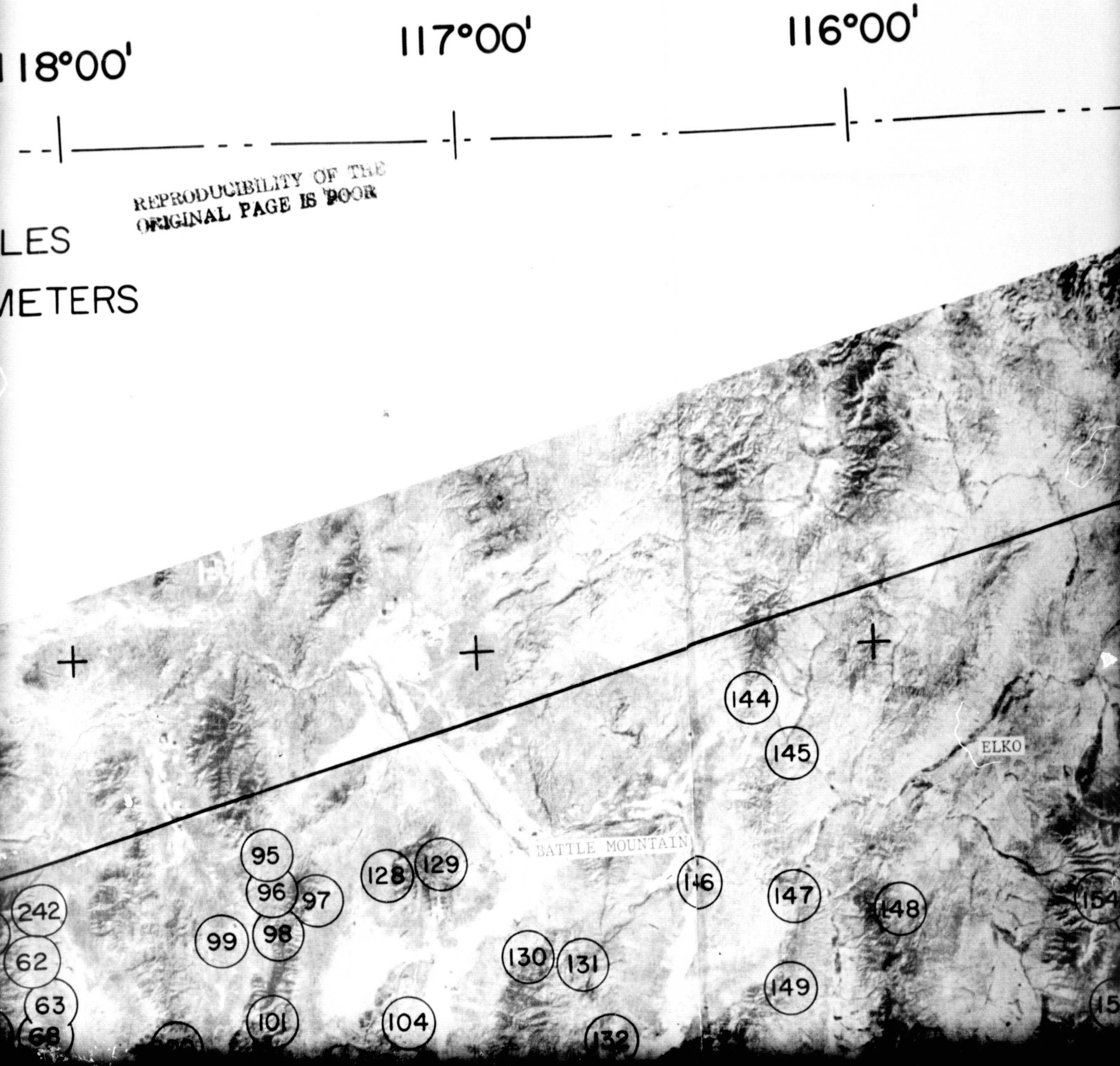
LANDSAT MOS



US METAL MINING DISTRICTS WIT

SAIC OF UTAH-NEVADA STUDY

NASA CONTR



THIN THE UTAH-NEVADA TEST S

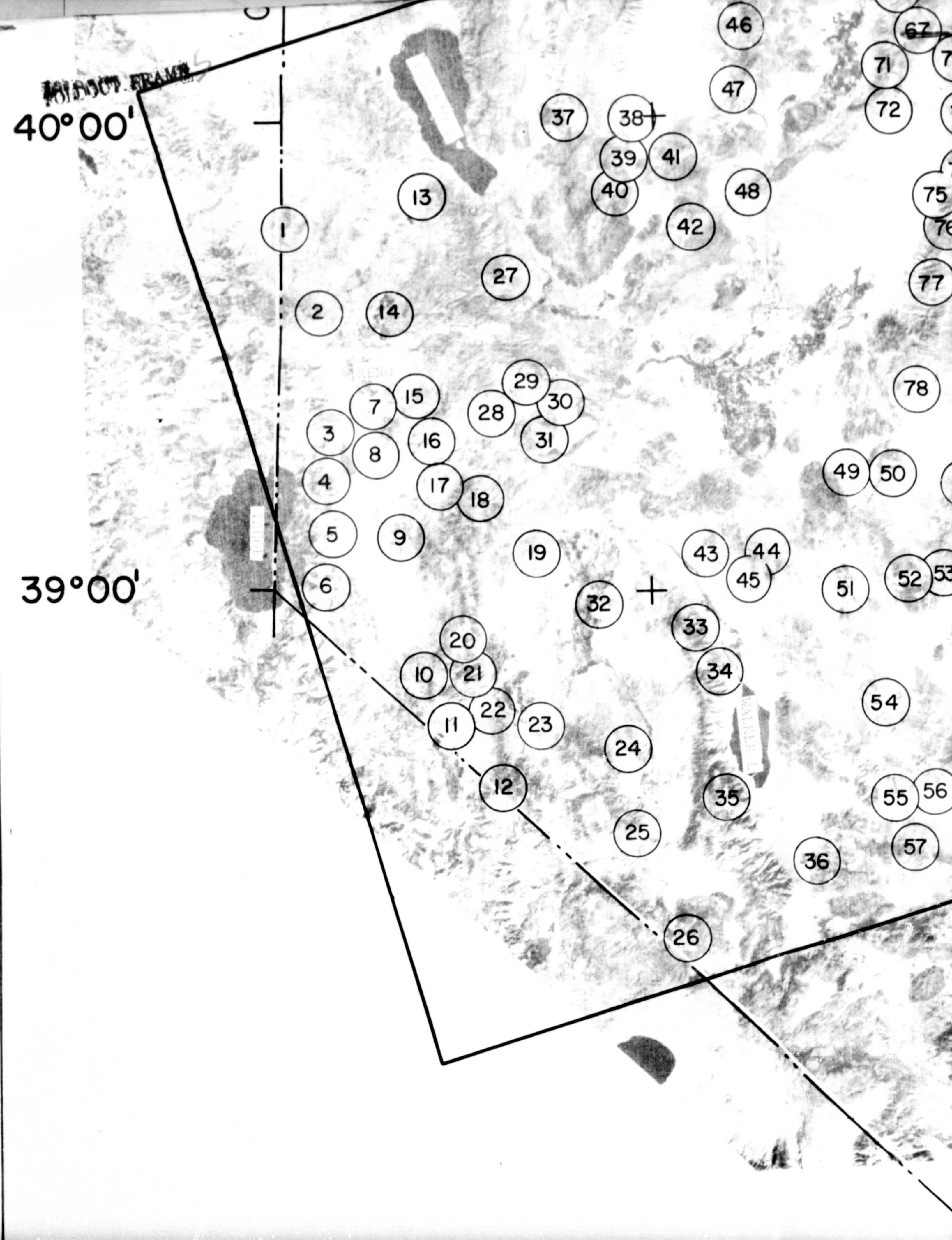
Y AREA, WITH MINING DISTRICT

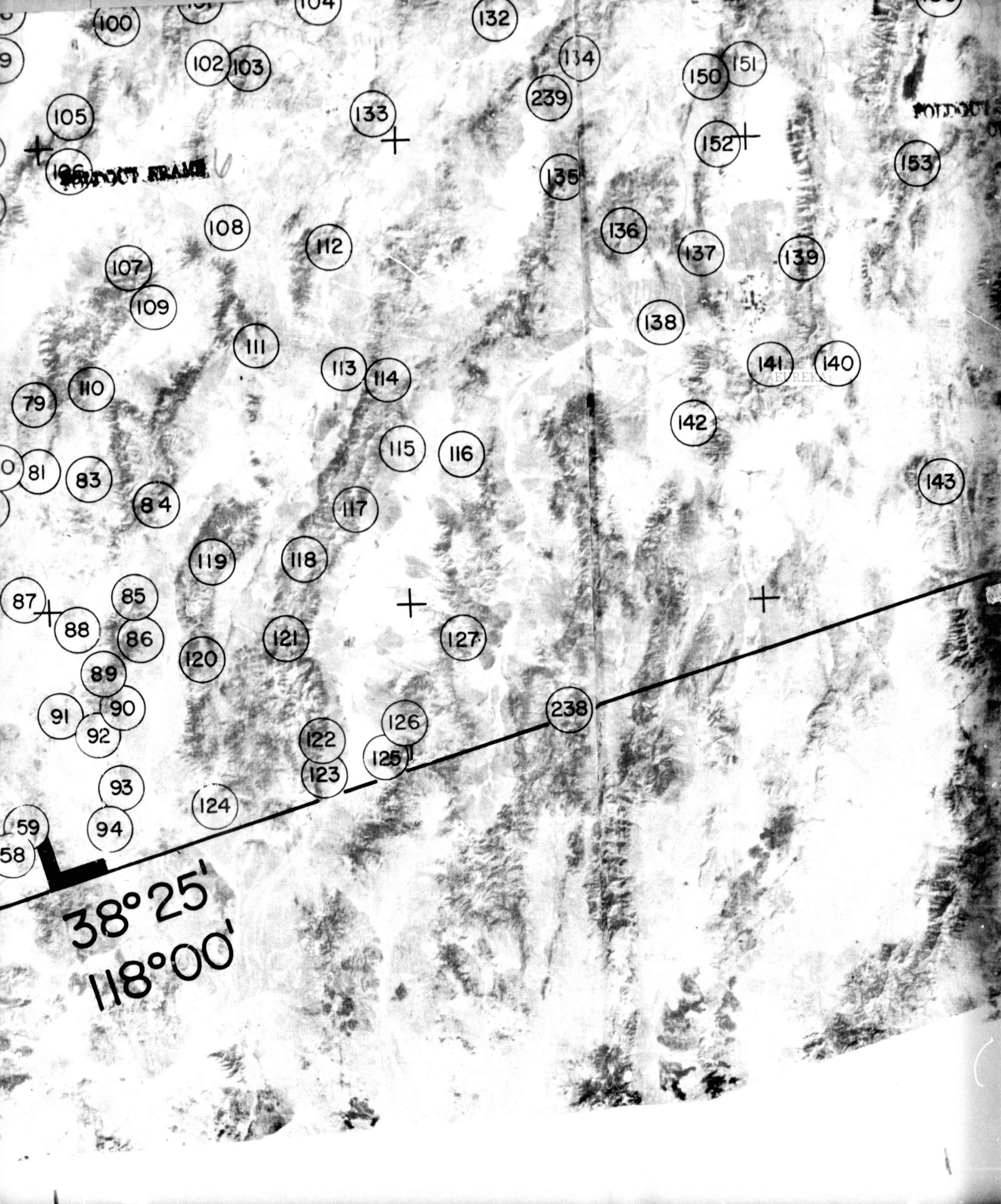
RACT NAS 5-20955

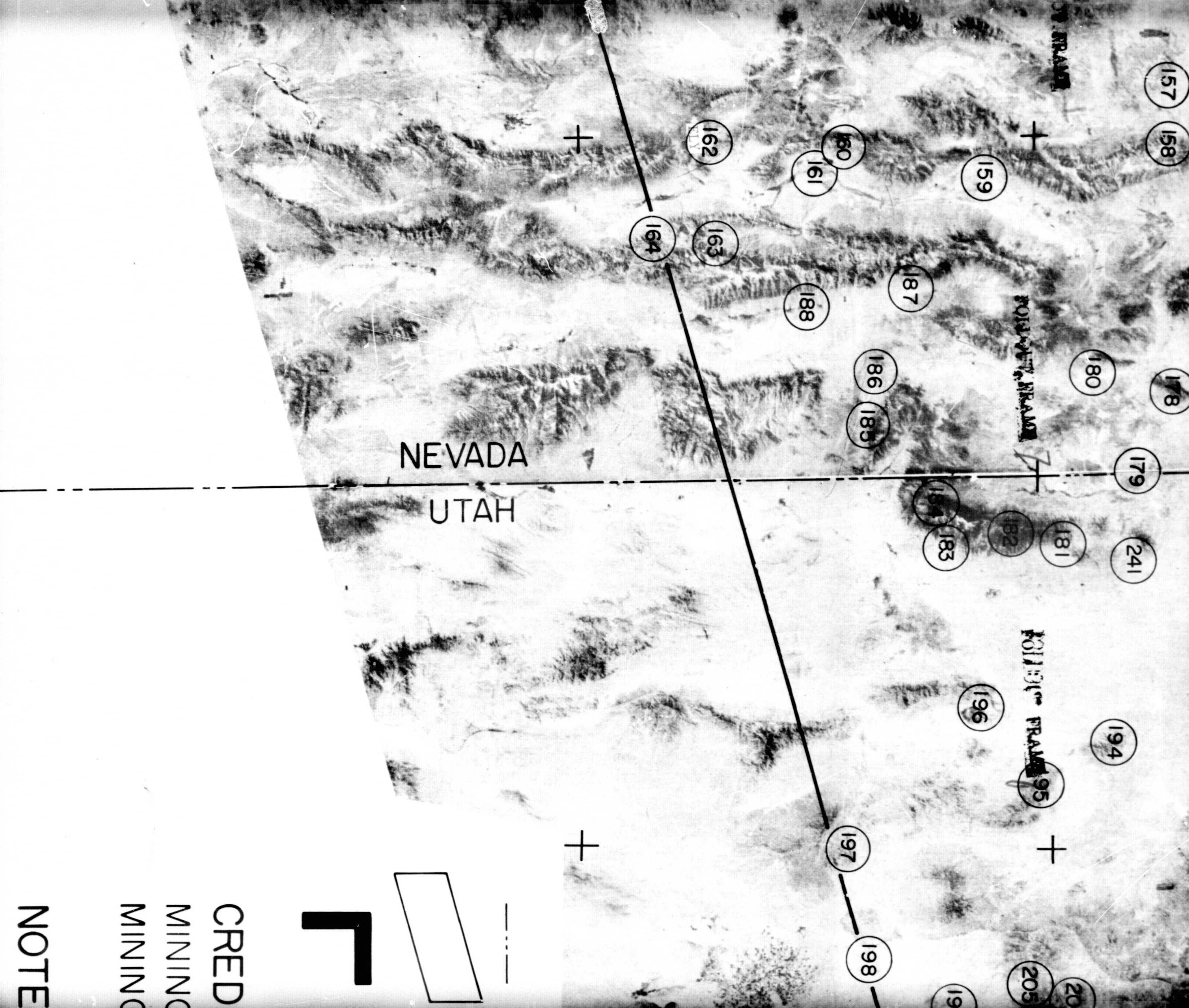
ST SITE SELECTED FOR THE

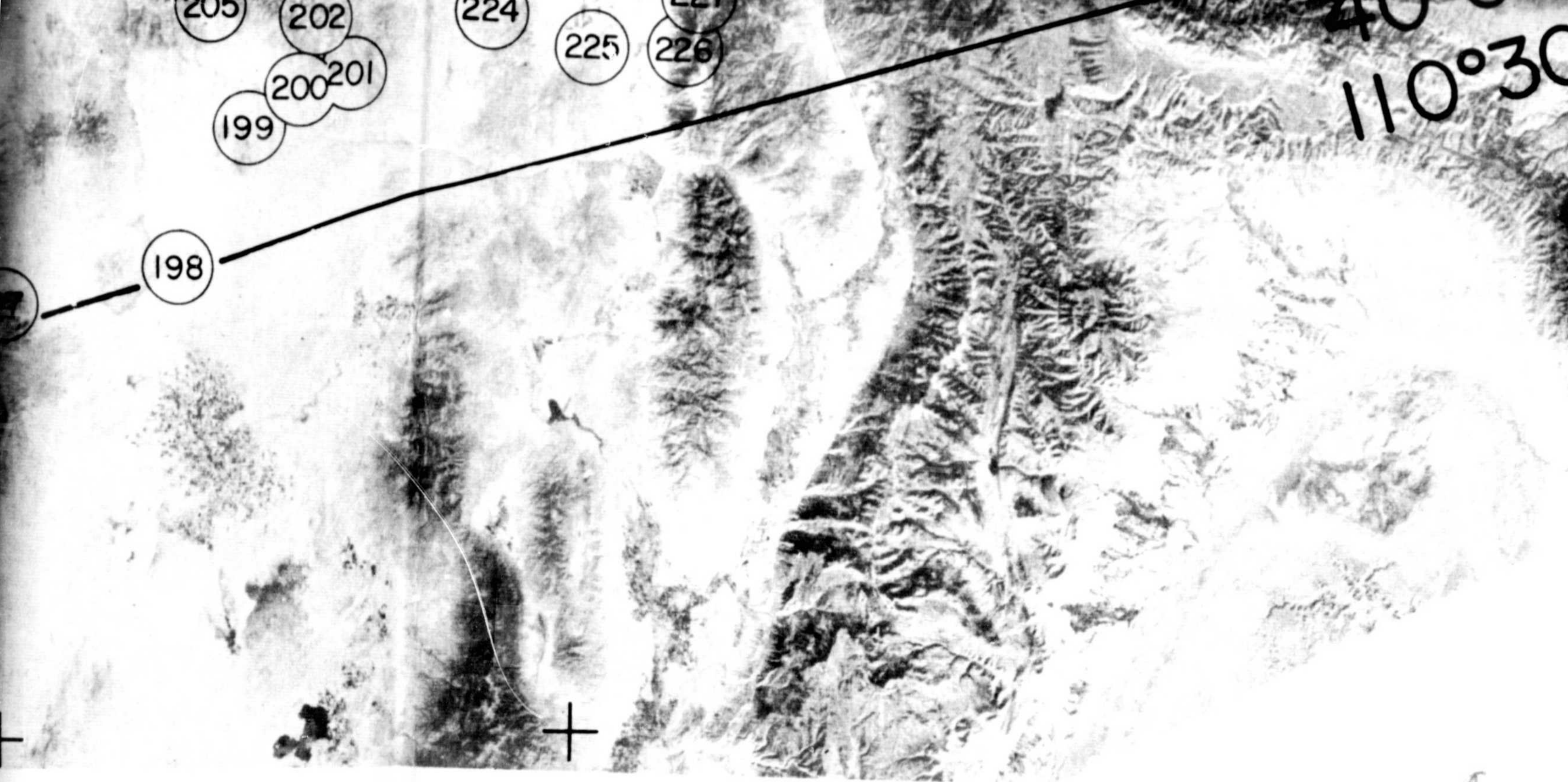
ICT LOCATIONS

FOLDOUT FRAME 4


40°00'
39°00'
RENO
WALKER L
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
67
71
72
75
76
77
78


100
104
132
102
103
134
150
151
105
133
239
152
106
FOLDOUT FRAME
135
153
108
112
136
137
139
107
109
138
111
113
114
141
140
110
79
142
115
116
81
83
84
143
117
119
118
87
85
88
86
121
127
120
89
238
90
91
126
92
122
125
123
93
124
59
94
58
38°25'
118°00'


NEVADA
UTAH
157
158
159
160
161
162
163
164
178
179
180
181
182
183
184
185
186
187
188
194
196
197
198
241



FOLDOUT FRAME 1

—··— STATE BOUNDARIES

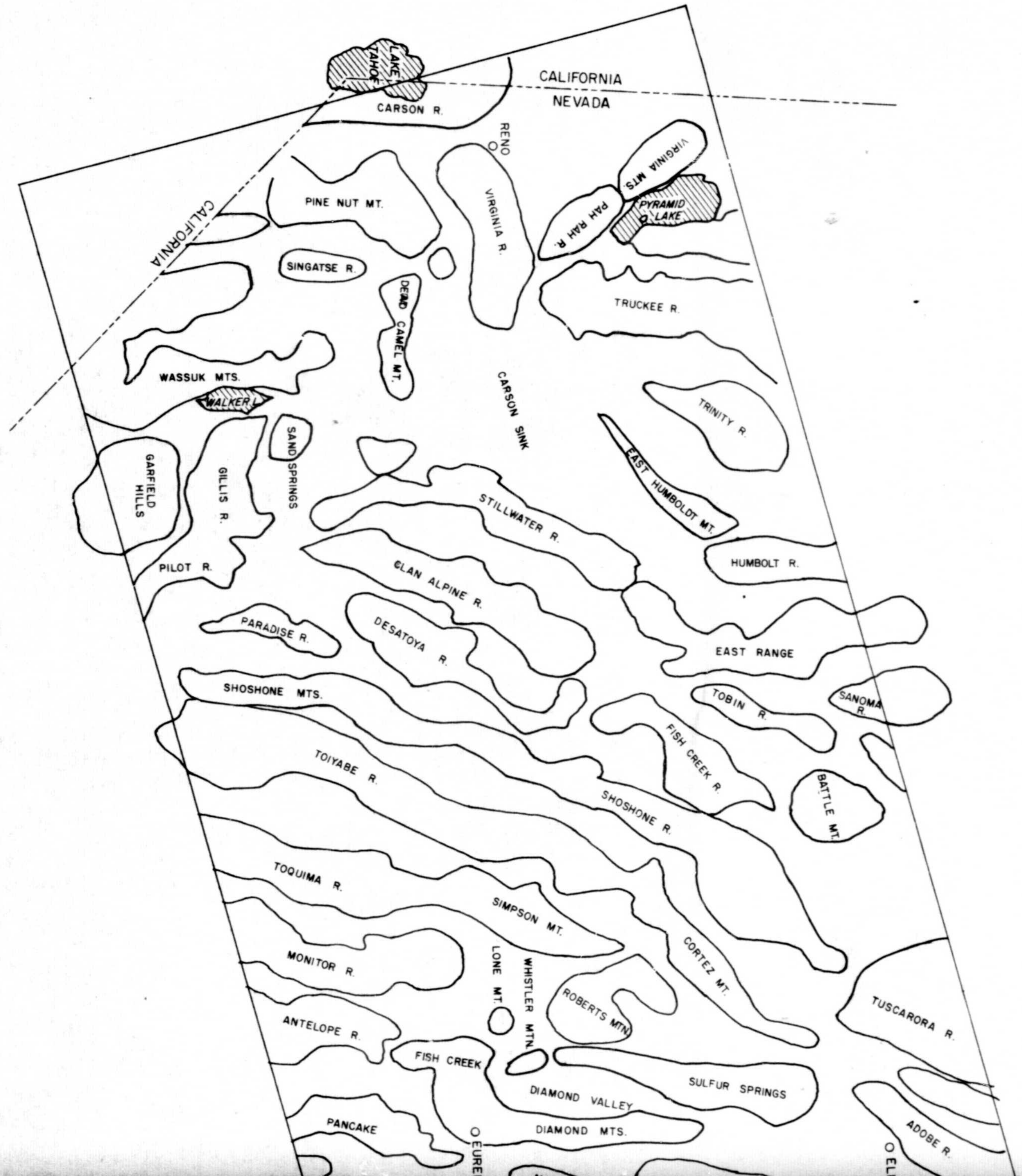
OPERATIONAL BOUNDARY

DESIGNATED TEST SITE COORDINATES

CREDIT: DISTRICT LOCATIONS COMPILED FROM–
MINING DISTRICTS & MINERAL DEPOSITS OF UTAH,
MINING DISTRICTS & MINERAL DEPOSITS OF NEVADA

NOTE: 234 MINING DISTRICT NUMBER REFERENCED TO ACCOMPANYING TABLE.

PLATE I


LAKE TAHOE
CALIFORNIA
NEVADA
CARSON R.
RENO
VIRGINIA MTS.
PINE NUT MT.
VIRGINIA R.
PAH RAH R.
PYRAMID LAKE
CALIFORNIA
SINGATSE R.
DEAD CAMEL MT.
TRUCKEE R.
CARSON SINK
WASSUK MTS.
WALKER L.
SAND SPRINGS
TRINITY R.
EAST HUMBOLDT MT.
GARFIELD HILLS
GILLIS R.
STILLWATER R.
HUMBOLT R.
PILOT R.
CLAN ALPINE R.
PARADISE R.
DESATOYA R.
EAST RANGE
SHOSHONE MTS.
TOBIN R.
SANOMA R.
FISH CREEK R.
TOIYABE R.
SHOSHONE R.
BATTLE MT.
TOQUIMA R.
SIMPSON MT.
CORTEZ MT.
MONITOR R.
LONE MT.
WHISTLER MTN.
ROBERTS MTN.
TUSCARORA R.
ANTELOPE R.
FISH CREEK
DIAMOND VALLEY
SULFUR SPRINGS
PANCAKE
DIAMOND MTS.
ADOBE R.

FOLDOUT FRAME 2

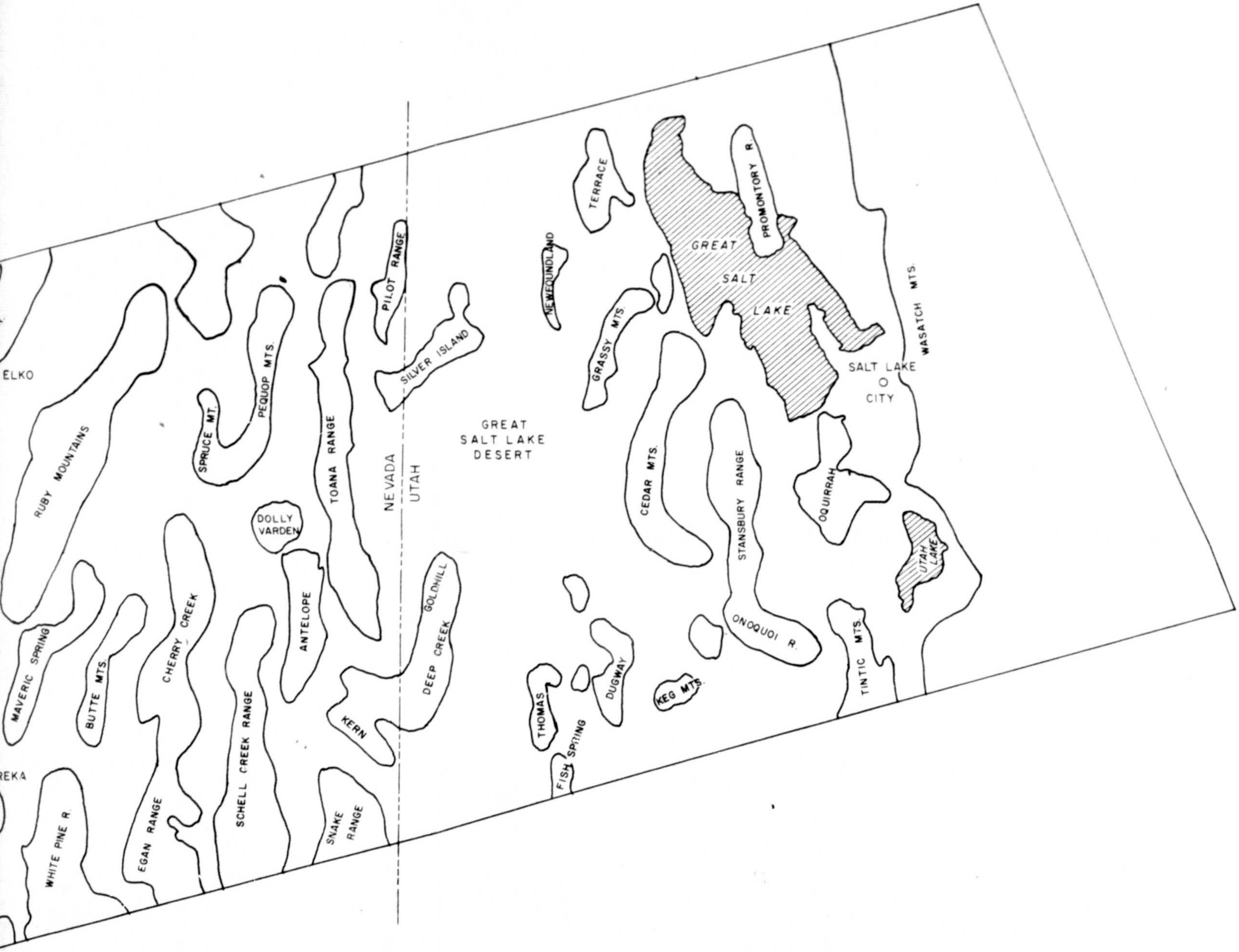


PLATE 2

LOCATIONS AND NAMES OF RANGES UTAH-NEVADA STUDY AREA

— Scale - 1:1,000,000

P-2

FOLDOUT FRAME

P. 3

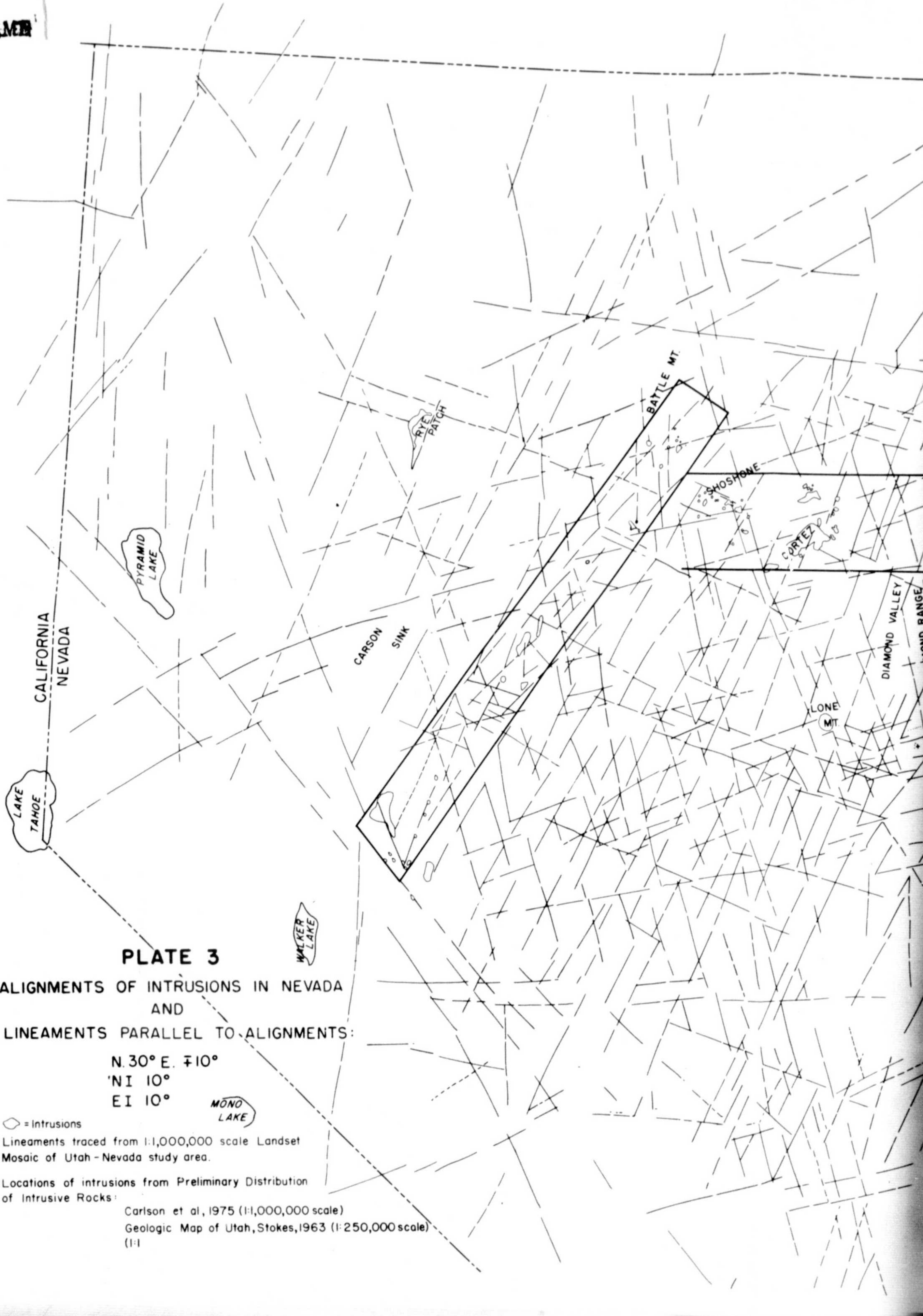


PLATE 3

ALIGNMENTS OF INTRUSIONS IN NEVADA
AND
LINEAMENTS PARALLEL TO ALIGNMENTS:

N. 30° E. ∓10°
'NI 10°
EI 10°

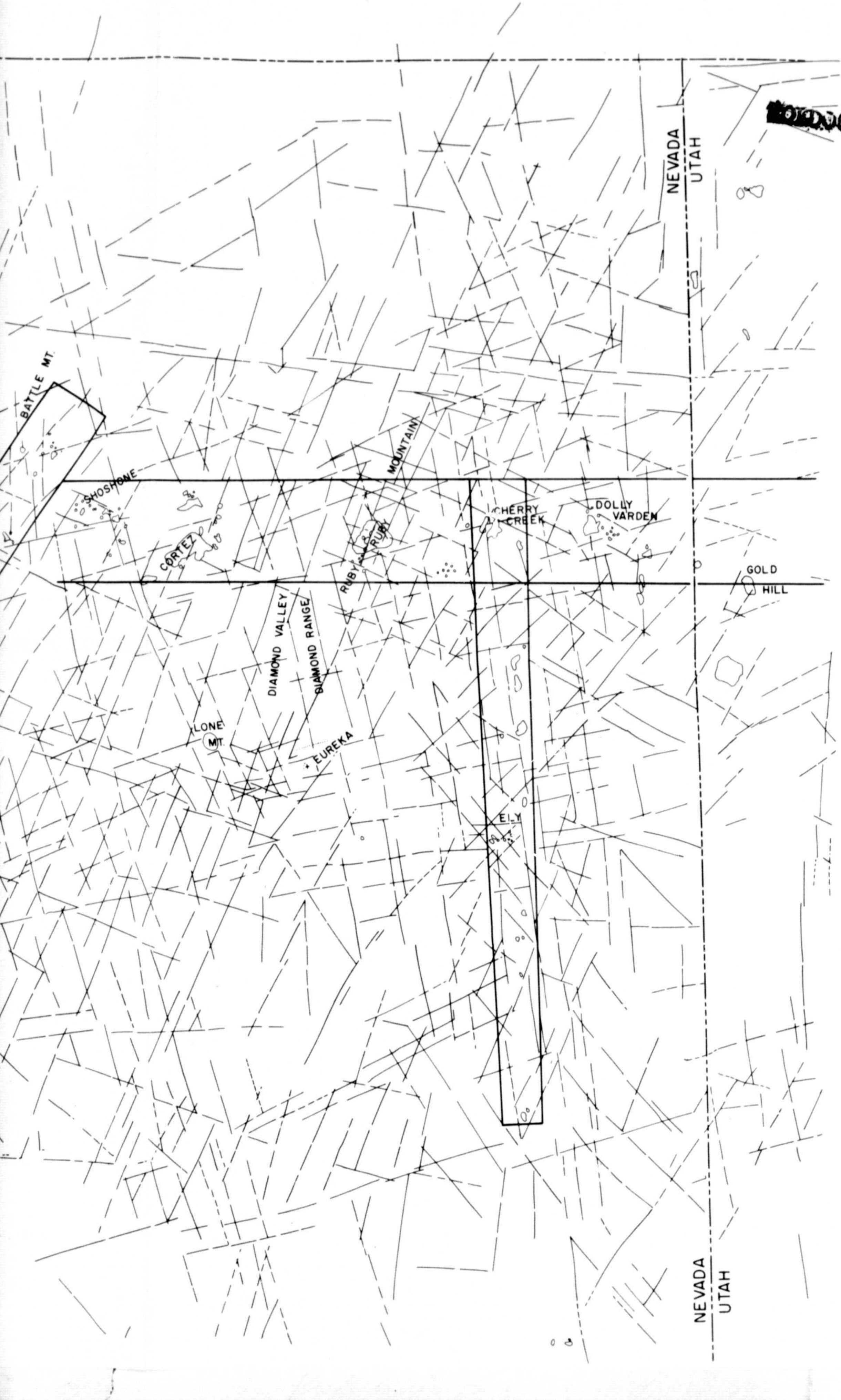
⬭ = Intrusions

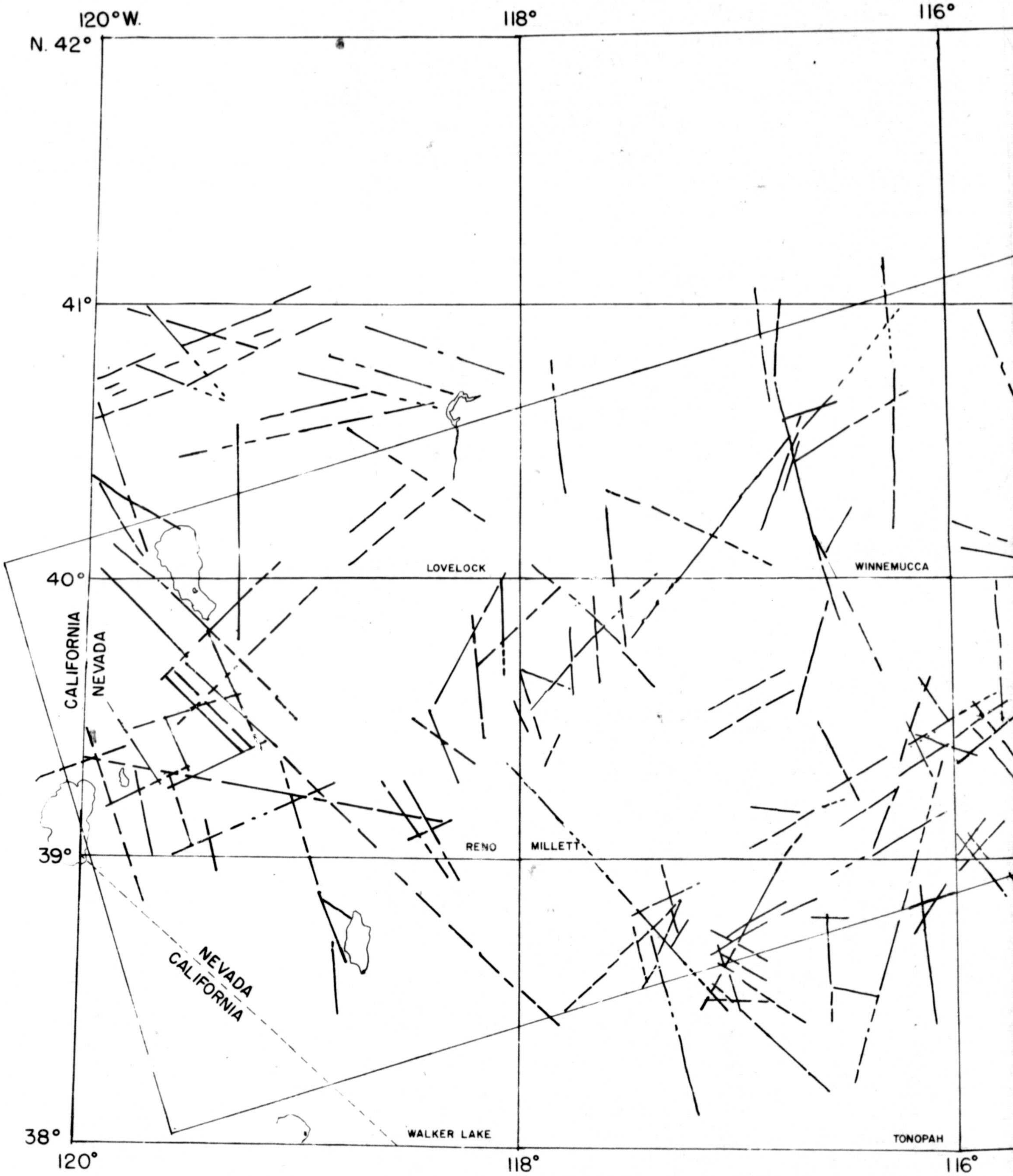
Lineaments traced from 1:1,000,000 scale Landset Mosaic of Utah - Nevada study area.

Locations of intrusions from Preliminary Distribution of Intrusive Rocks:

Carlson et al, 1975 (1:1,000,000 scale)
Geologic Map of Utah, Stokes, 1963 (1:250,000 scale)
(1:1

FRAME 2


NEVADA
UTAH
BATTLE MT.
SHOSHONE
CORTEZ
RUBY MOUNTAIN
RUBY
CHERRY CREEK
DOLLY VARDEN
GOLD HILL
DIAMOND VALLEY
DIAMOND RANGE
LONE MT.
EUREKA
ELY
NEVADA
UTAH


120°W.
118°
116°
N. 42°
41°
40°
39°
38°
120°
118°
116°
LOVELOCK
WINNEMUCCA
RENO
MILLETT
WALKER LAKE
TONOPAH
CALIFORNIA
NEVADA
NEVADA
CALIFORNIA

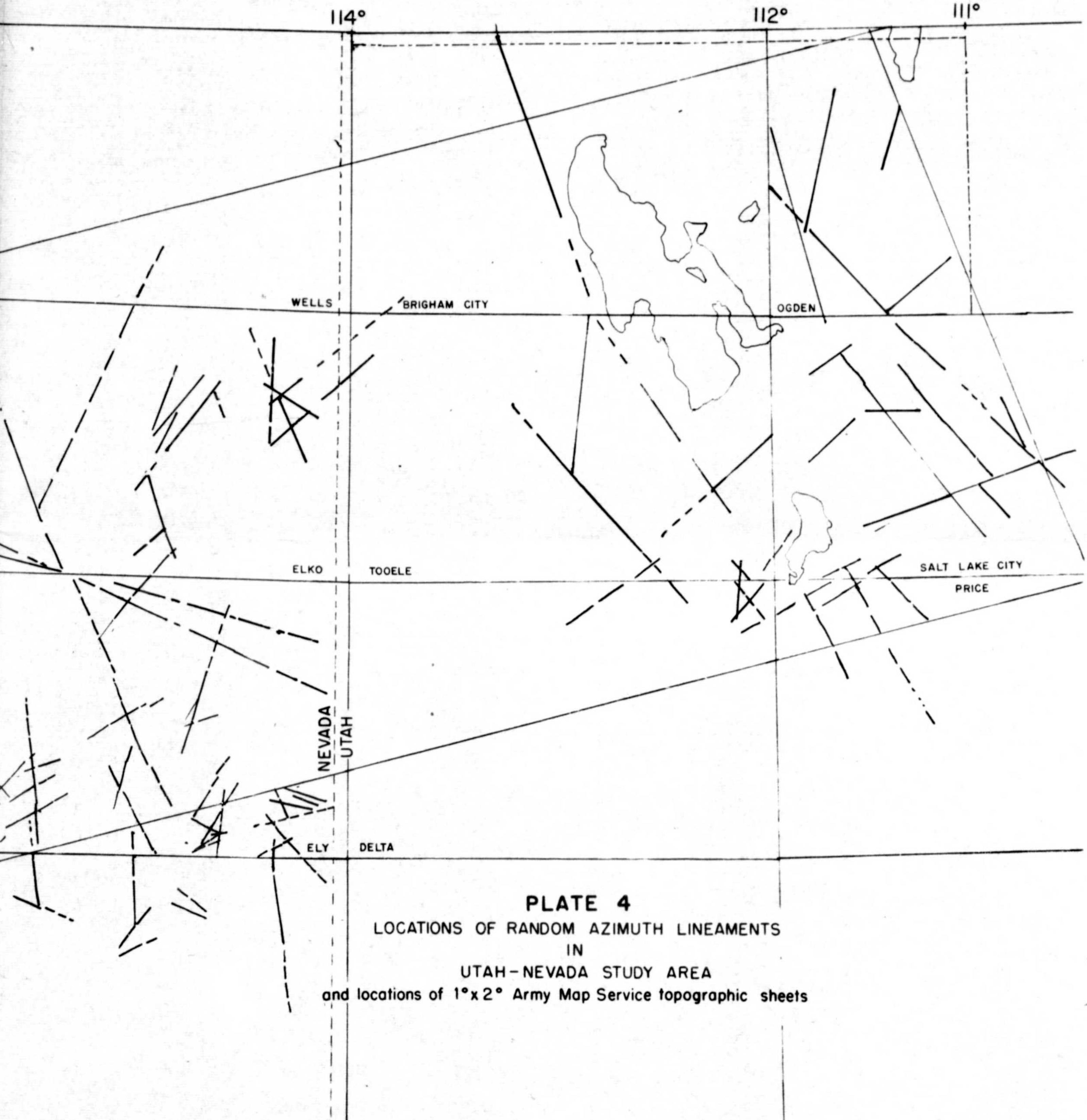
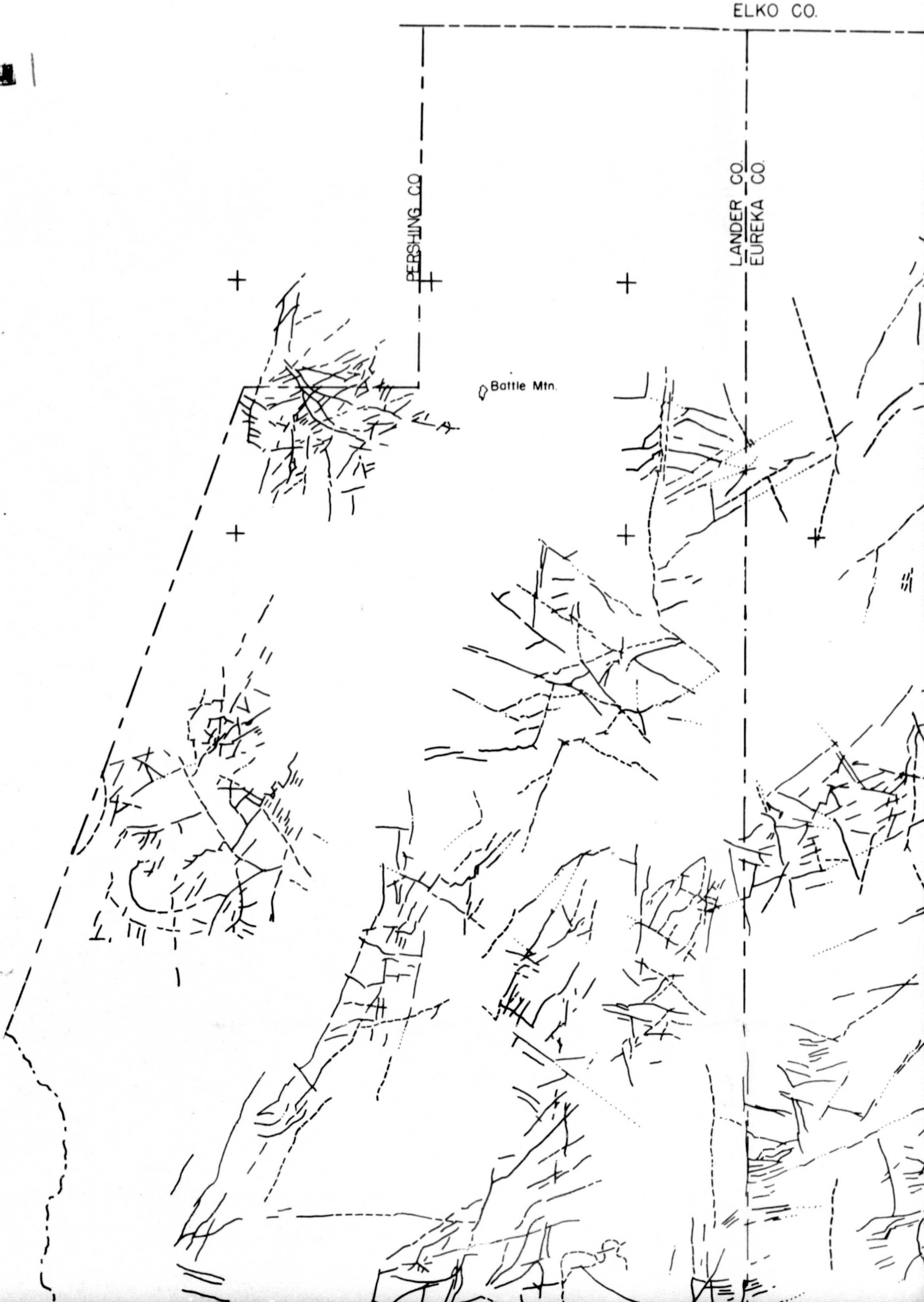
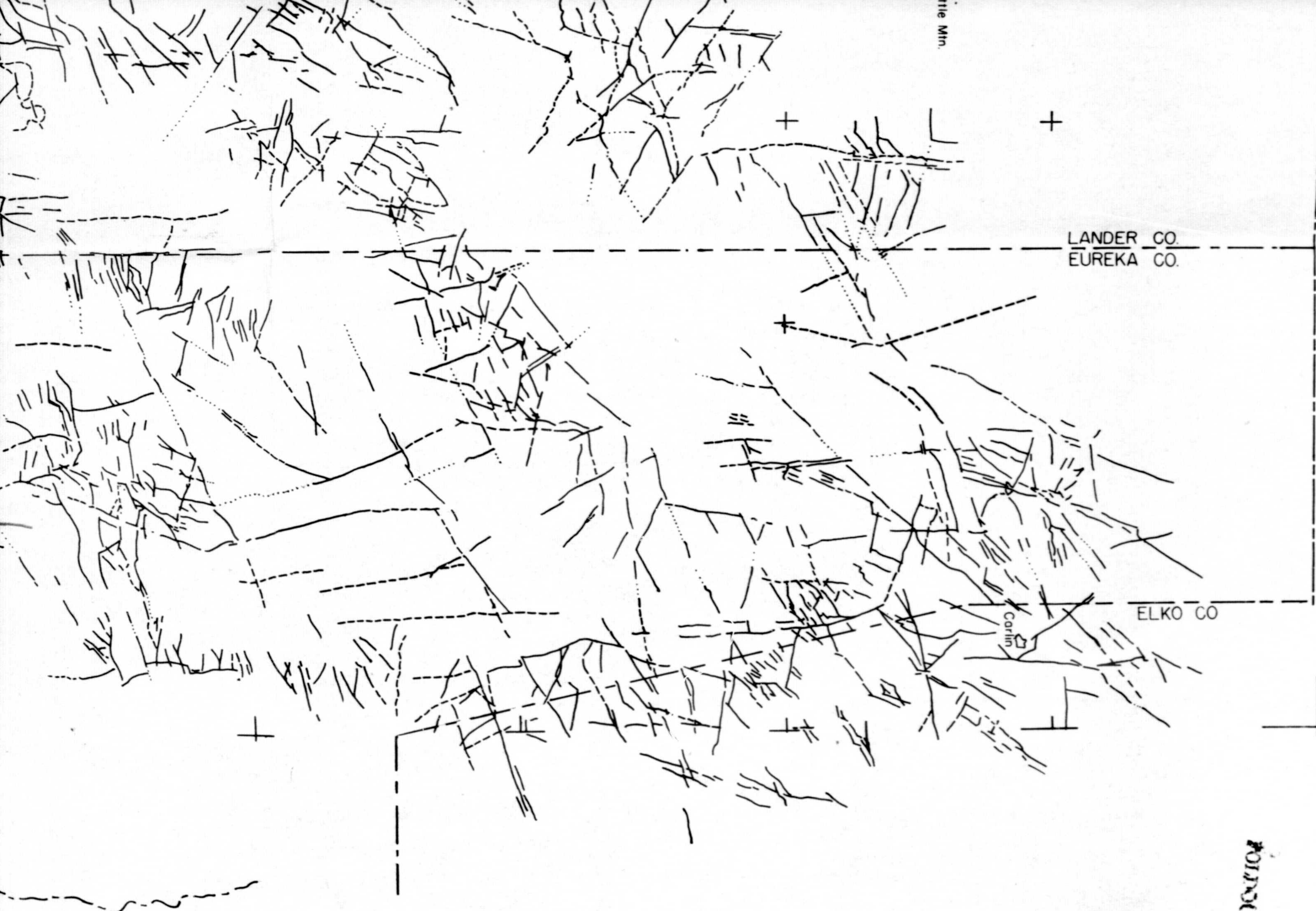


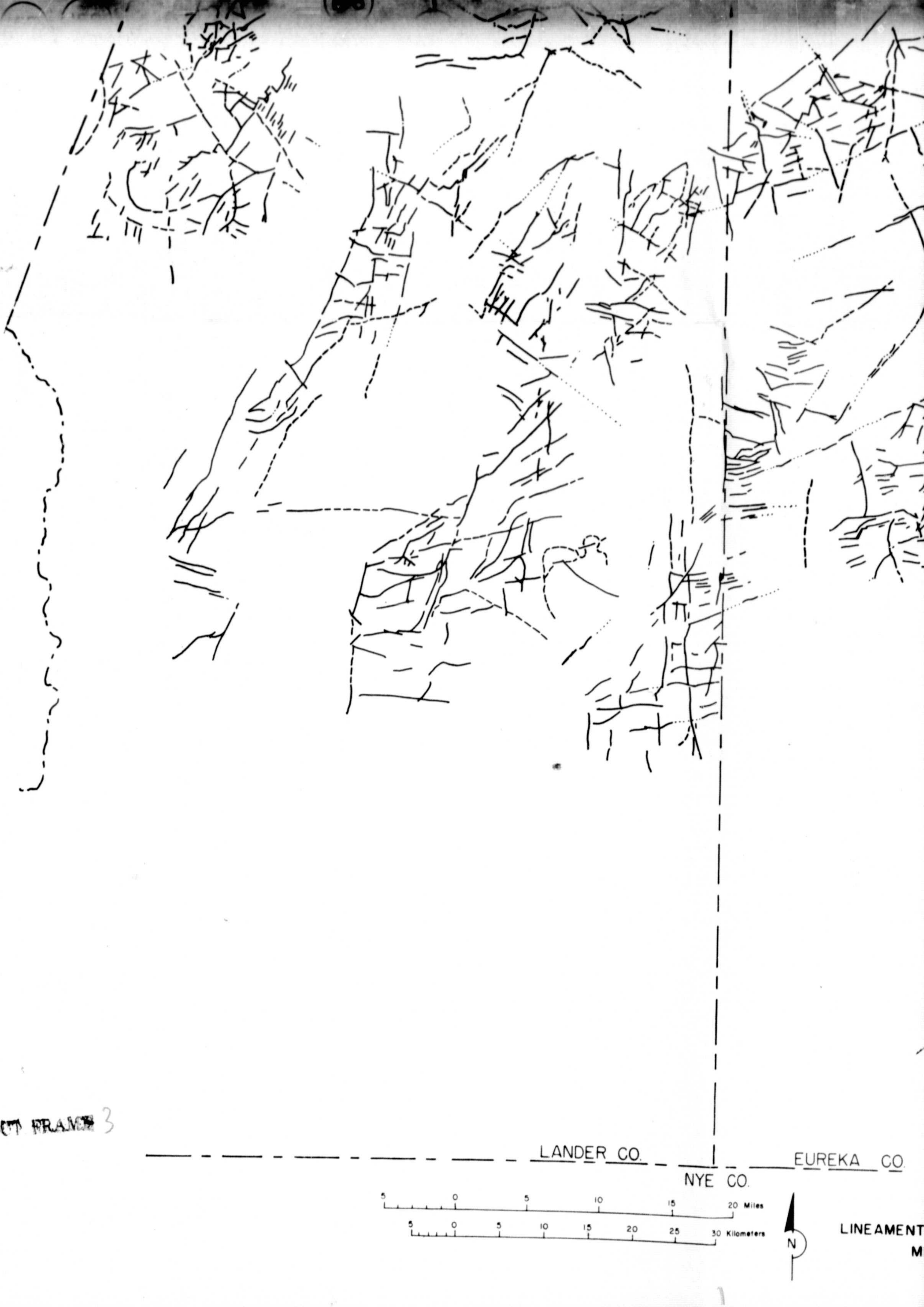
PLATE 4
LOCATIONS OF RANDOM AZIMUTH LINEAMENTS
IN
UTAH-NEVADA STUDY AREA
and locations of 1°x 2° Army Map Service topographic sheets

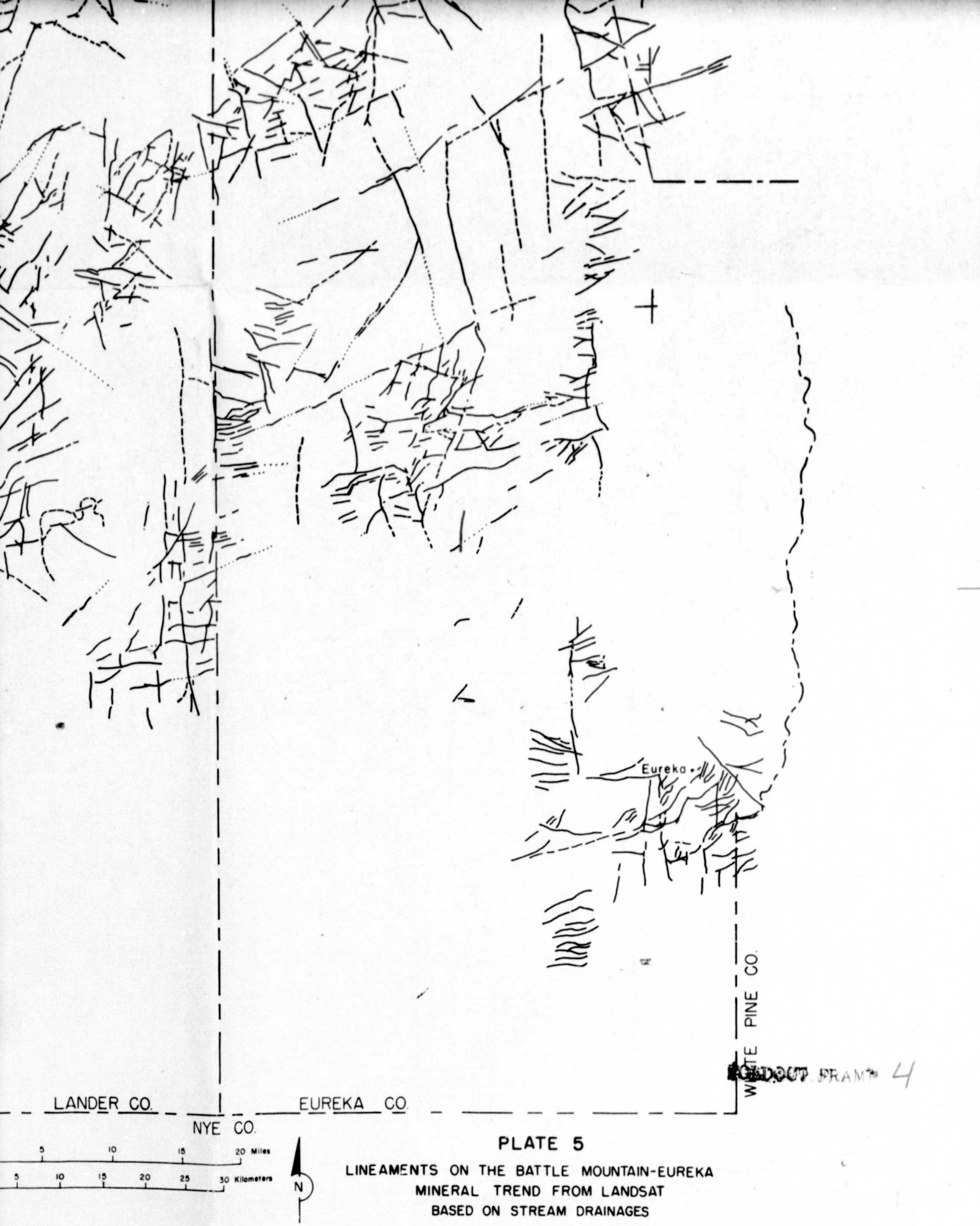
P-4


ELKO CO.
PERSHING CO
LANDER CO.
EUREKA CO.
Battle Mtn.



2

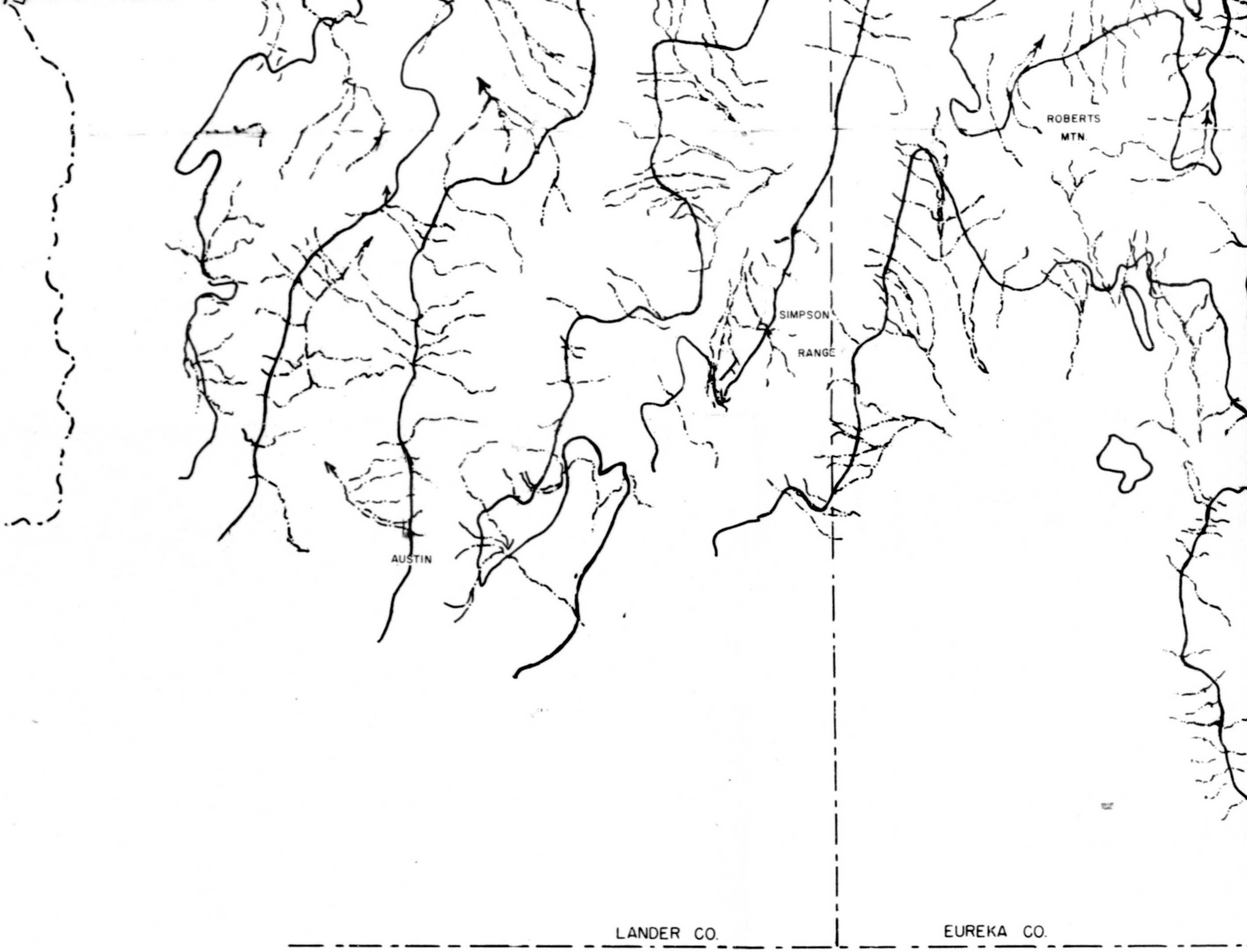

LANDER CO.
EUREKA CO.
NYE CO.
5 0 5 10 15 20 Miles
5 0 5 10 15 20 25 30 Kilometers
N
LINEAMENT
MI



FOLDOUT FRAME 4

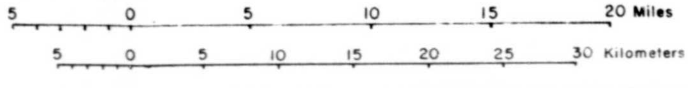
PLATE 5

LINEAMENTS ON THE BATTLE MOUNTAIN-EUREKA MINERAL TREND FROM LANDSAT BASED ON STREAM DRAINAGES

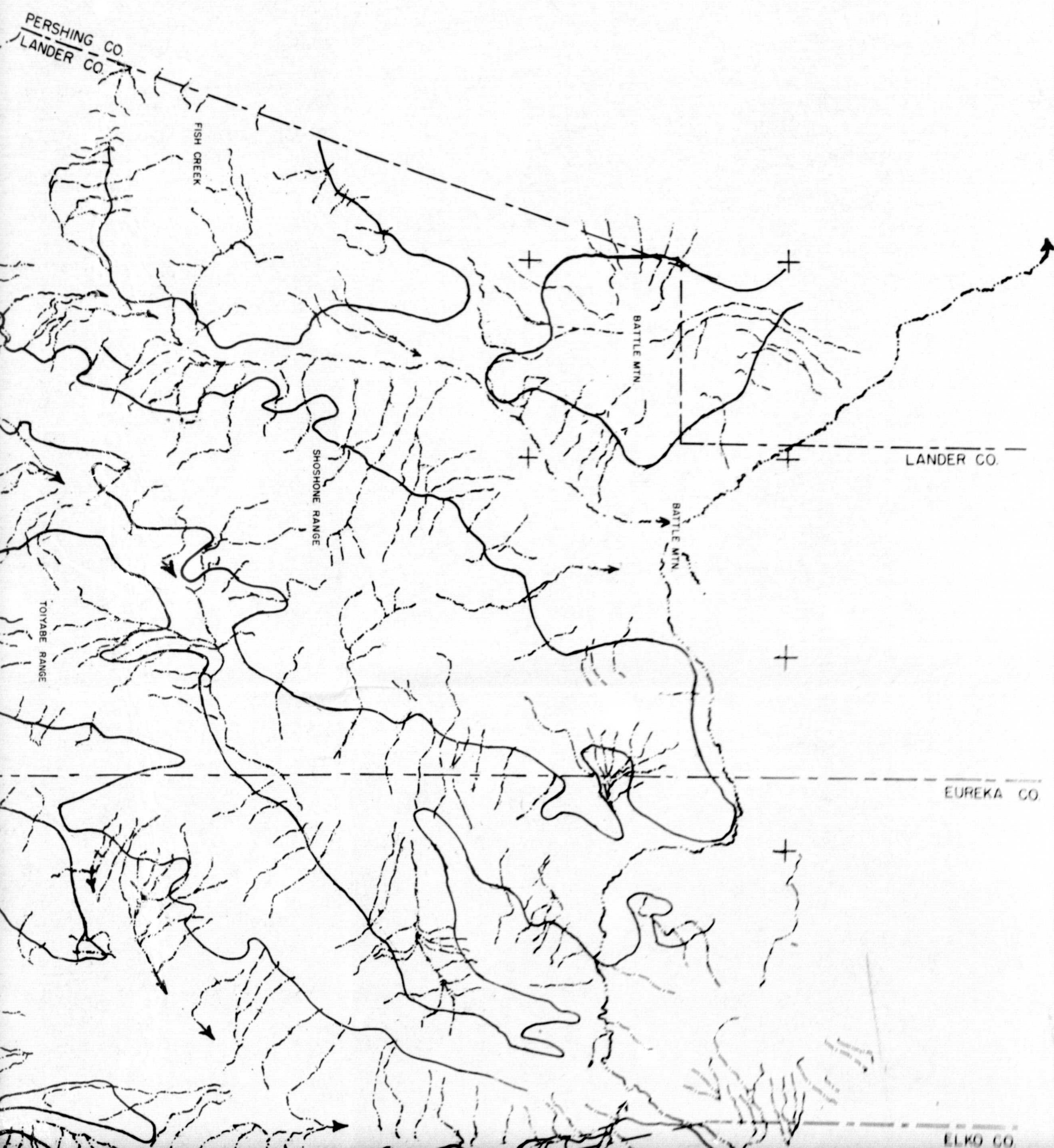


PLATE

DRAINAGE TRENDS



FOLDOUT FRAME



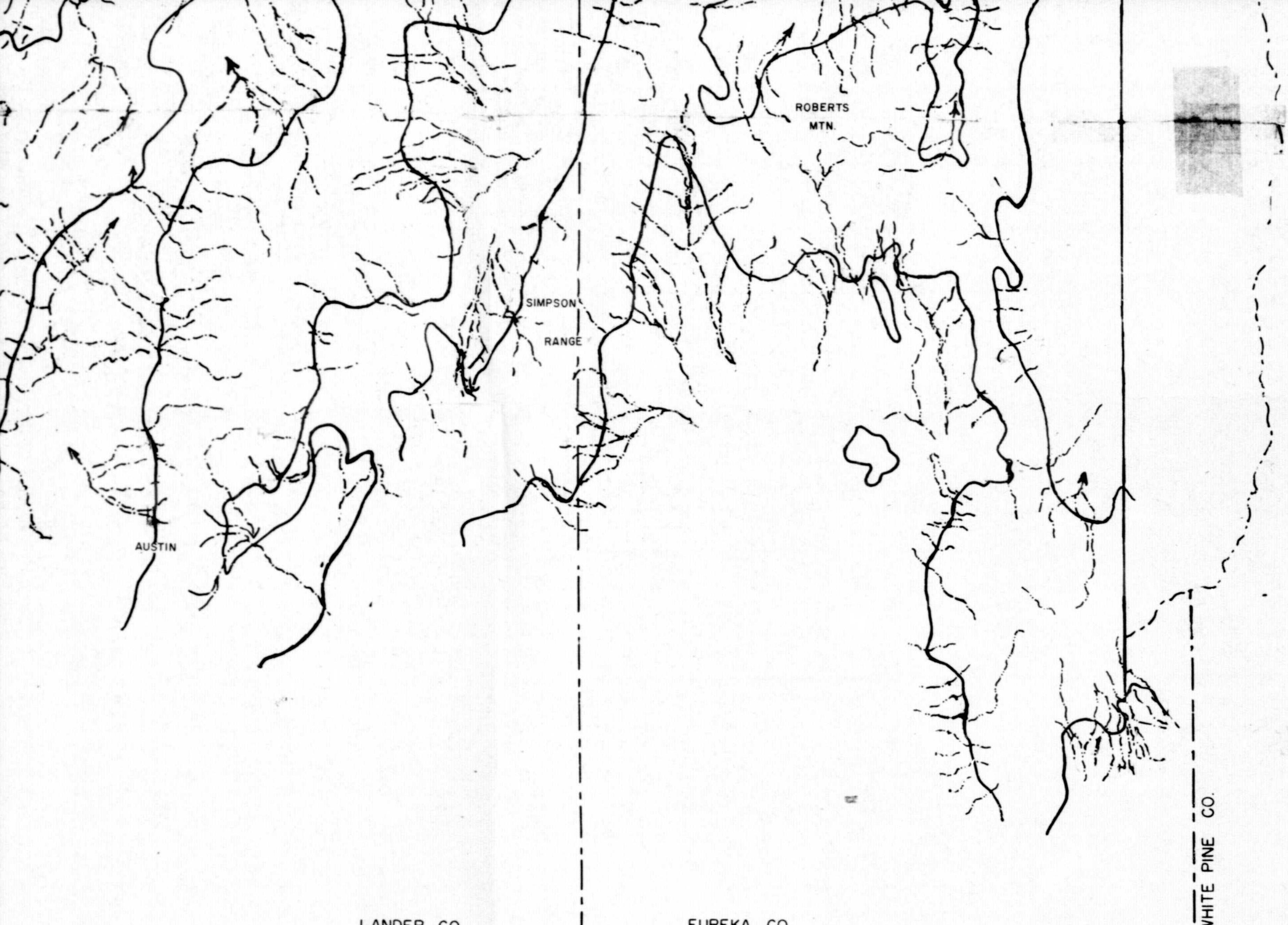
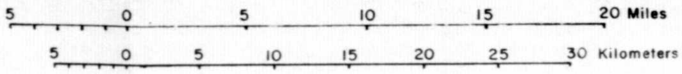
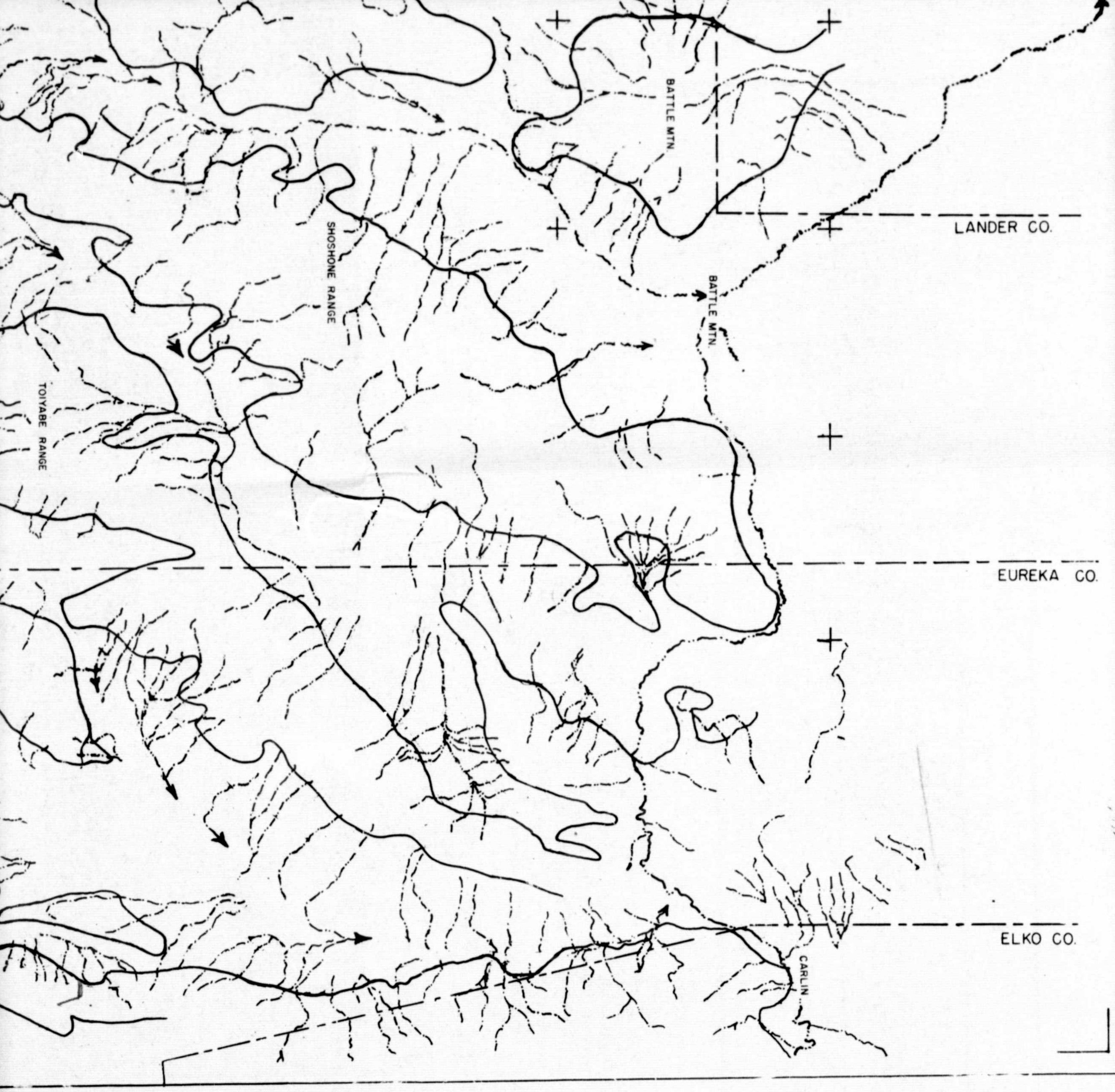


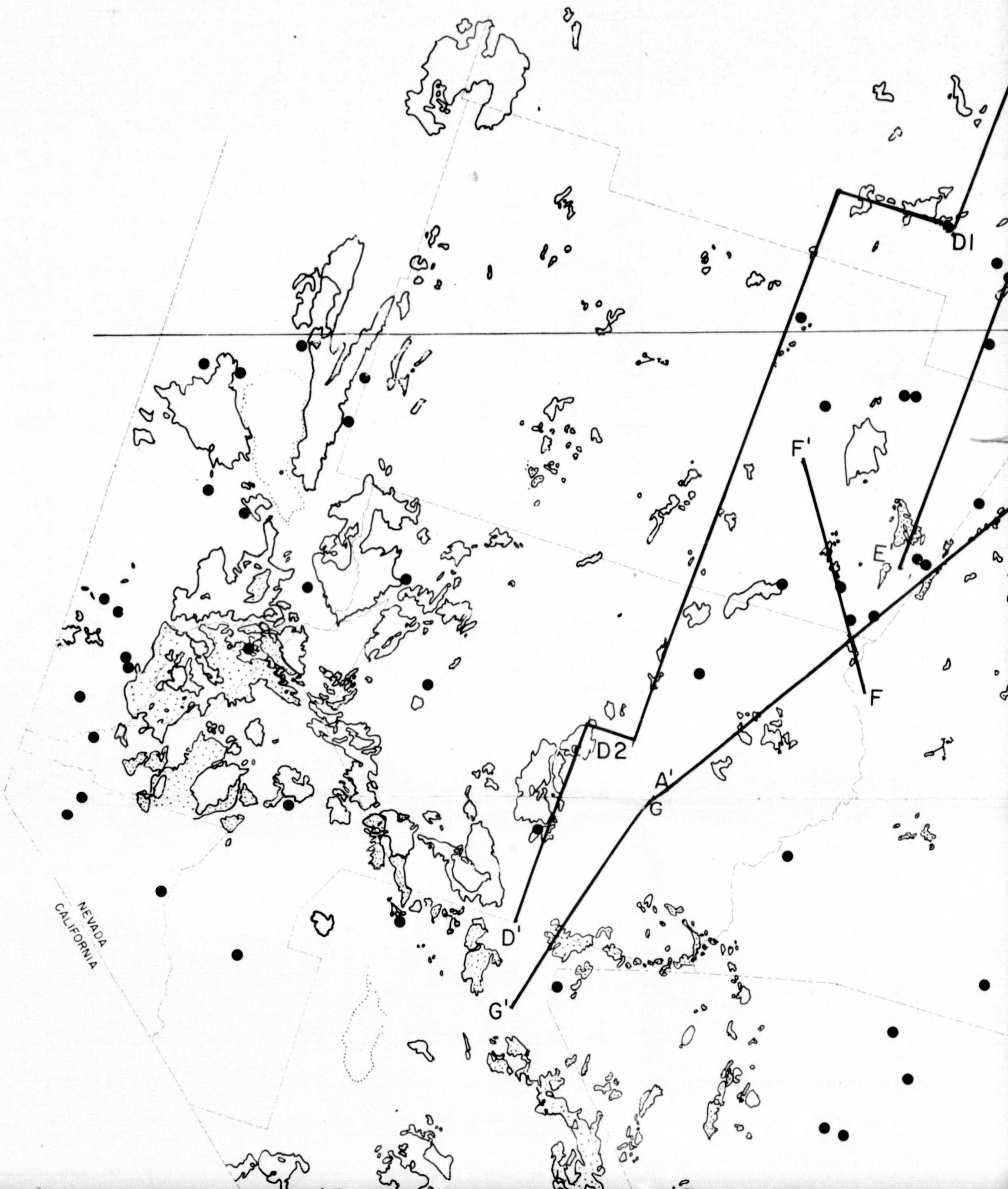
PLATE 6

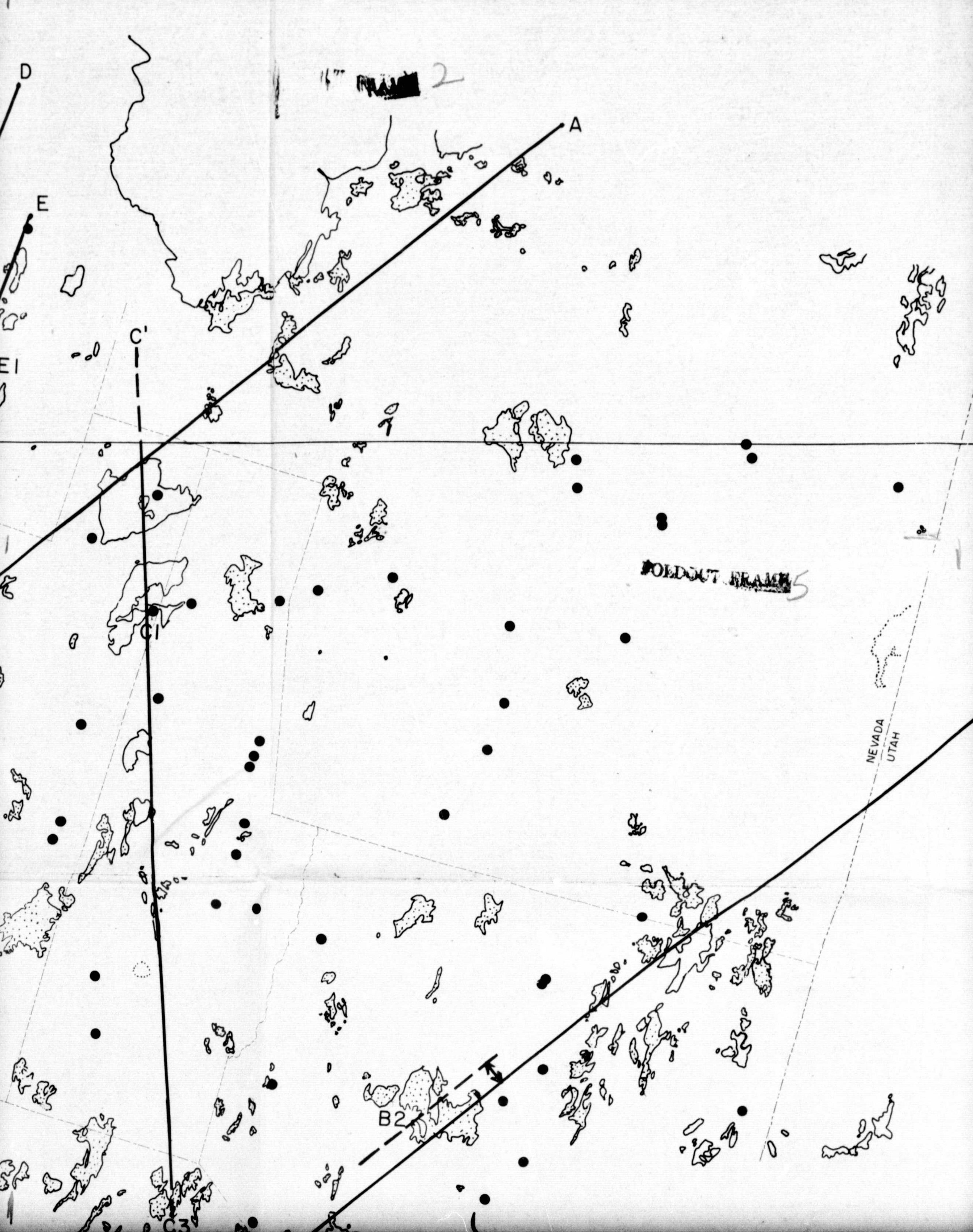
DRAINAGE TRENDS FROM A.M.S. SHEETS





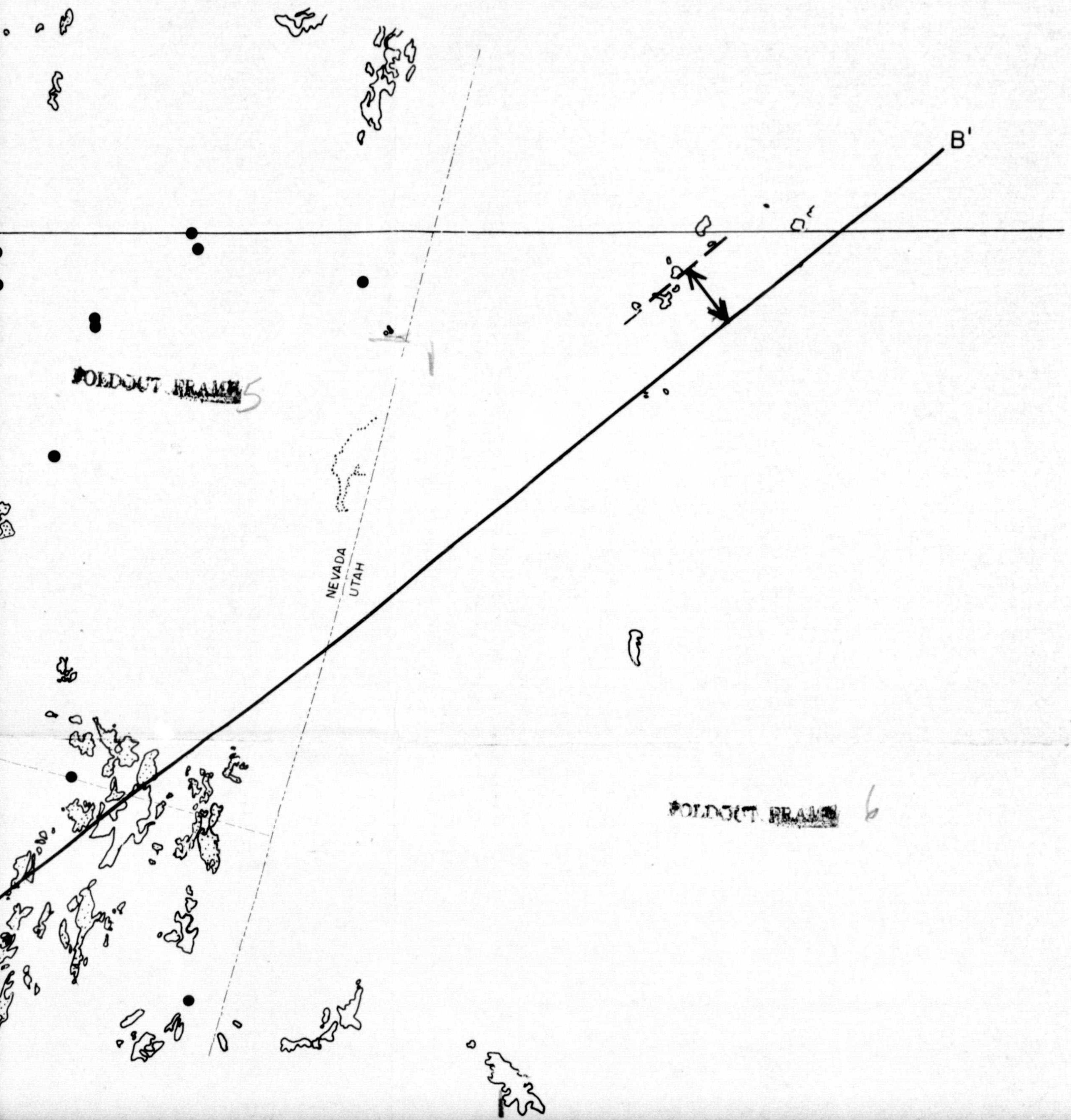
FOLDOUT FRAME 4


D1
F'
E
F
D2
A'
G
D'
G'
NEVADA
CALIFORNIA



FOLDOUT FRAME 2
A
D
E
E1
C'
C1
FOLDOUT FRAME 5
NEVADA
UTAH
B2
C3

FOLDOUT FRAME 3



FOLDOUT FRAME 5

FOLDOUT FRAME 6

FOLDOUT FRAME 4

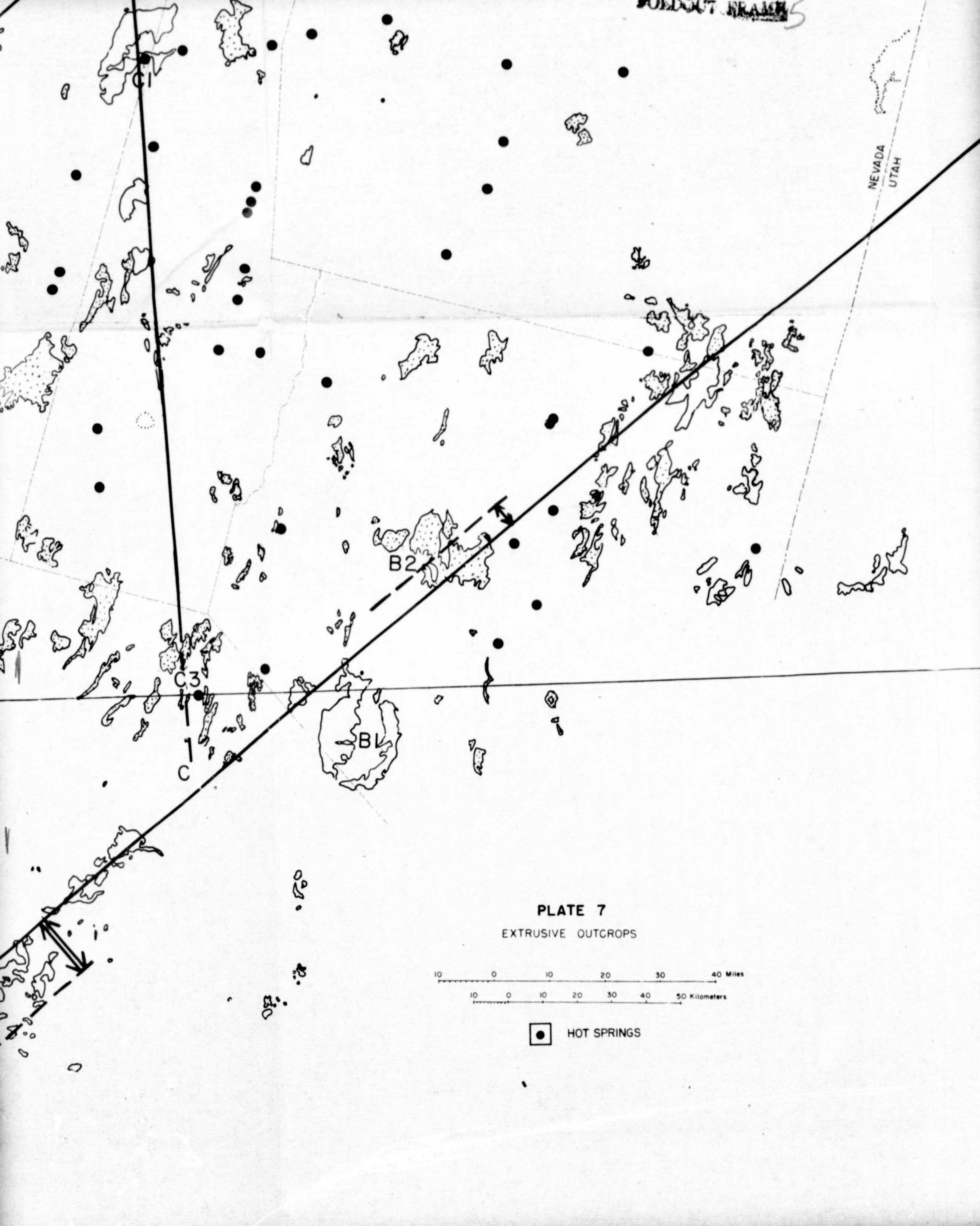
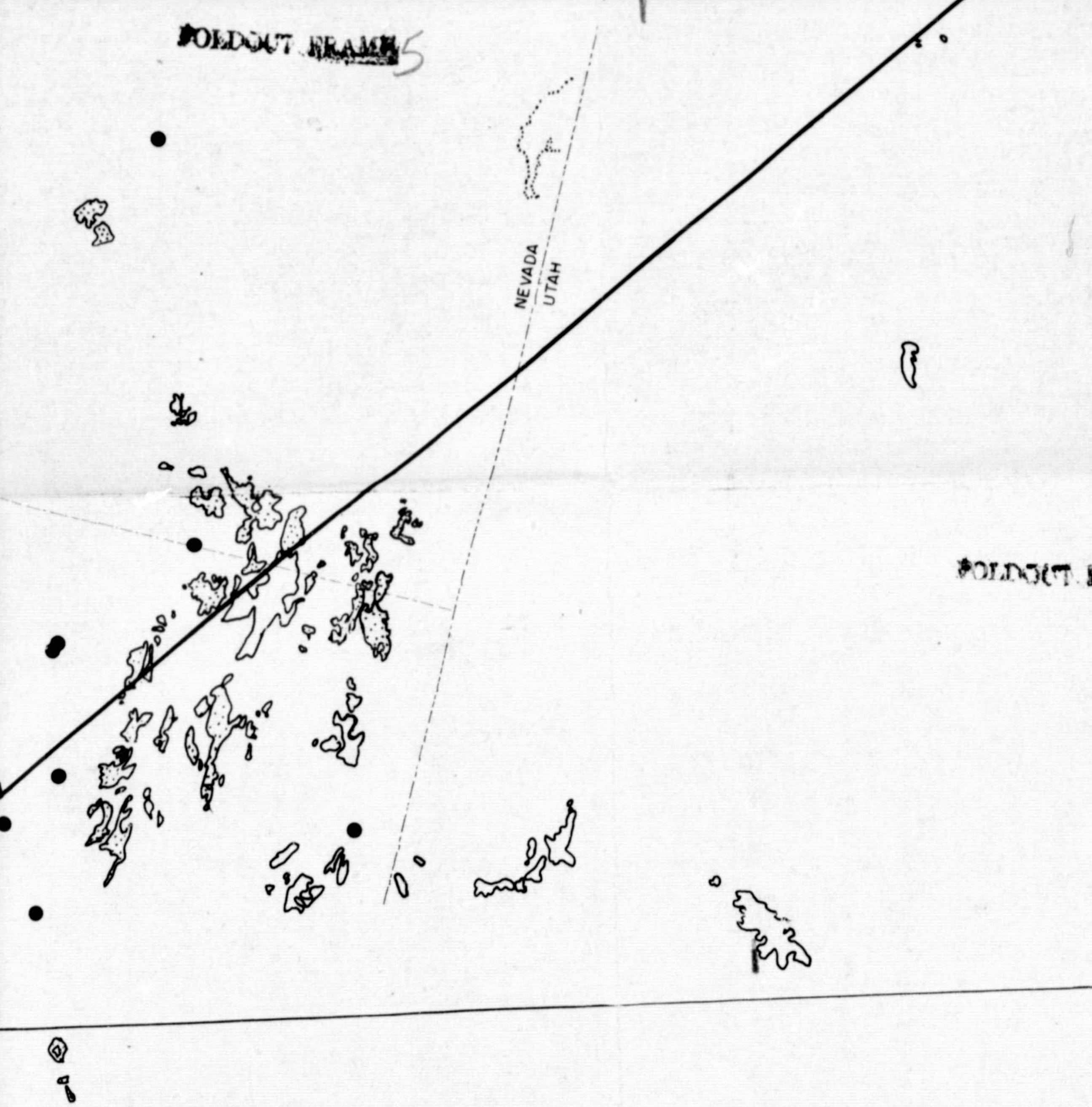


PLATE 7

EXTRUSIVE OUTCROPS

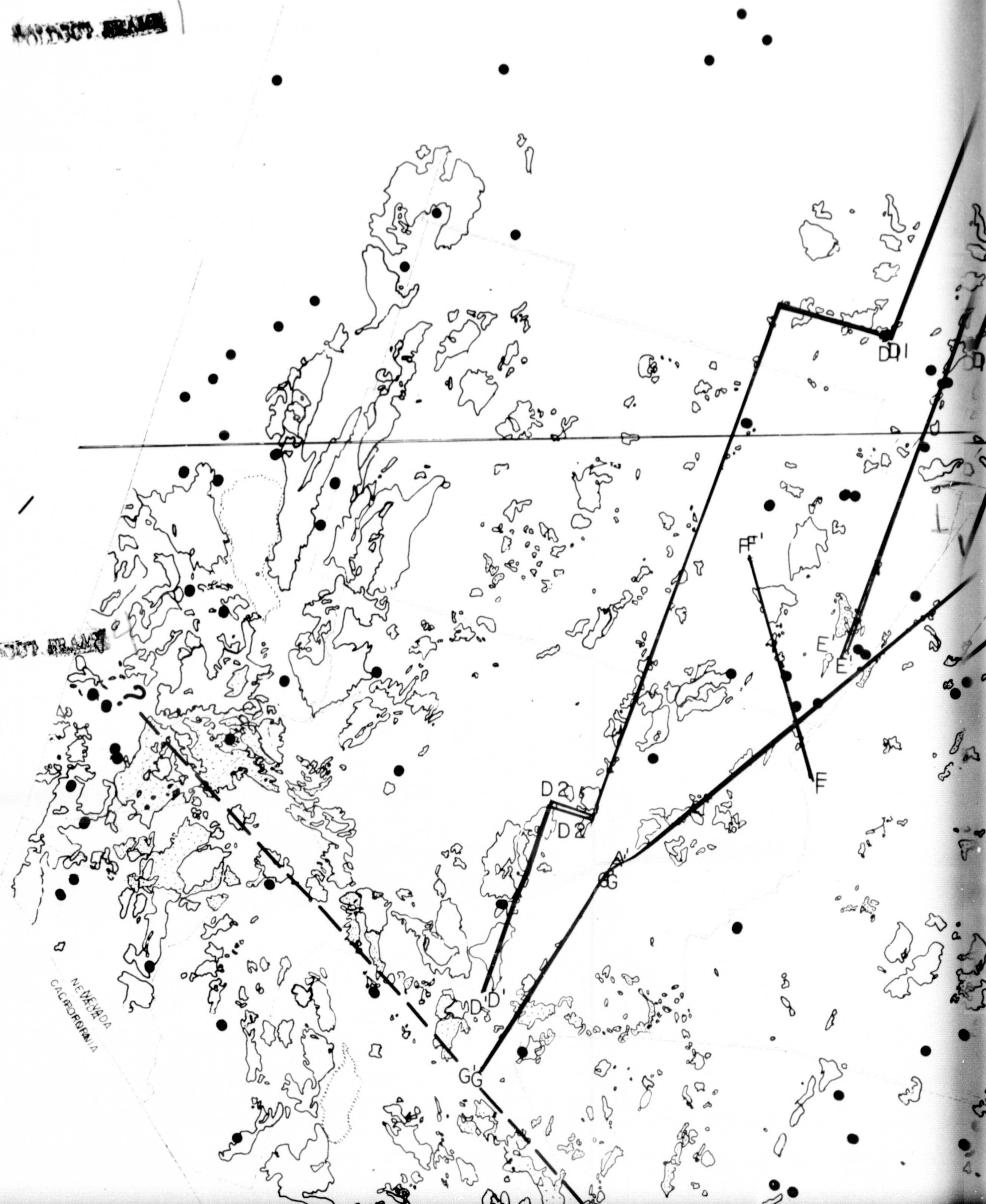
FOLDOUT FRAME 5

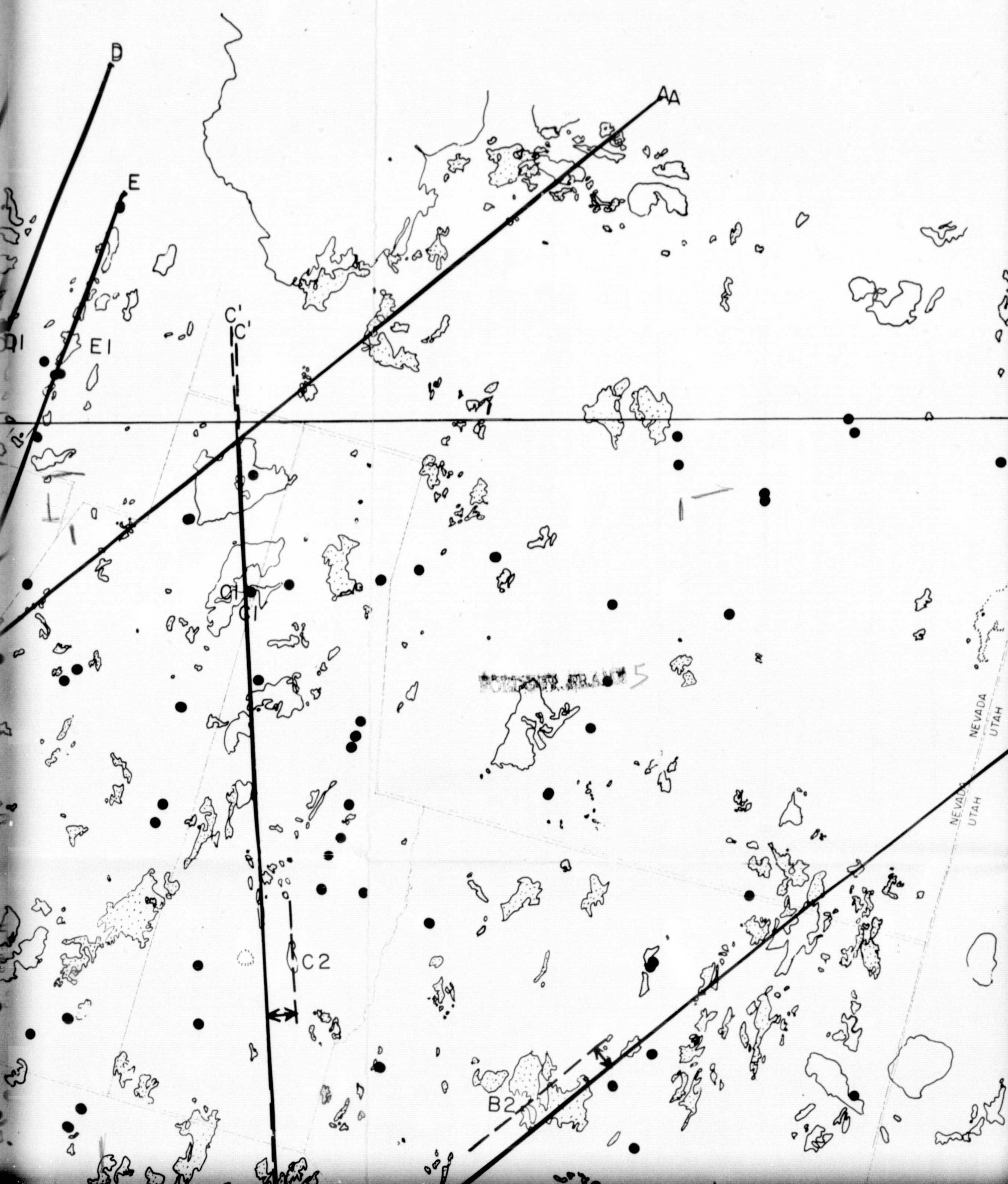


FOLDOUT FRAME 6

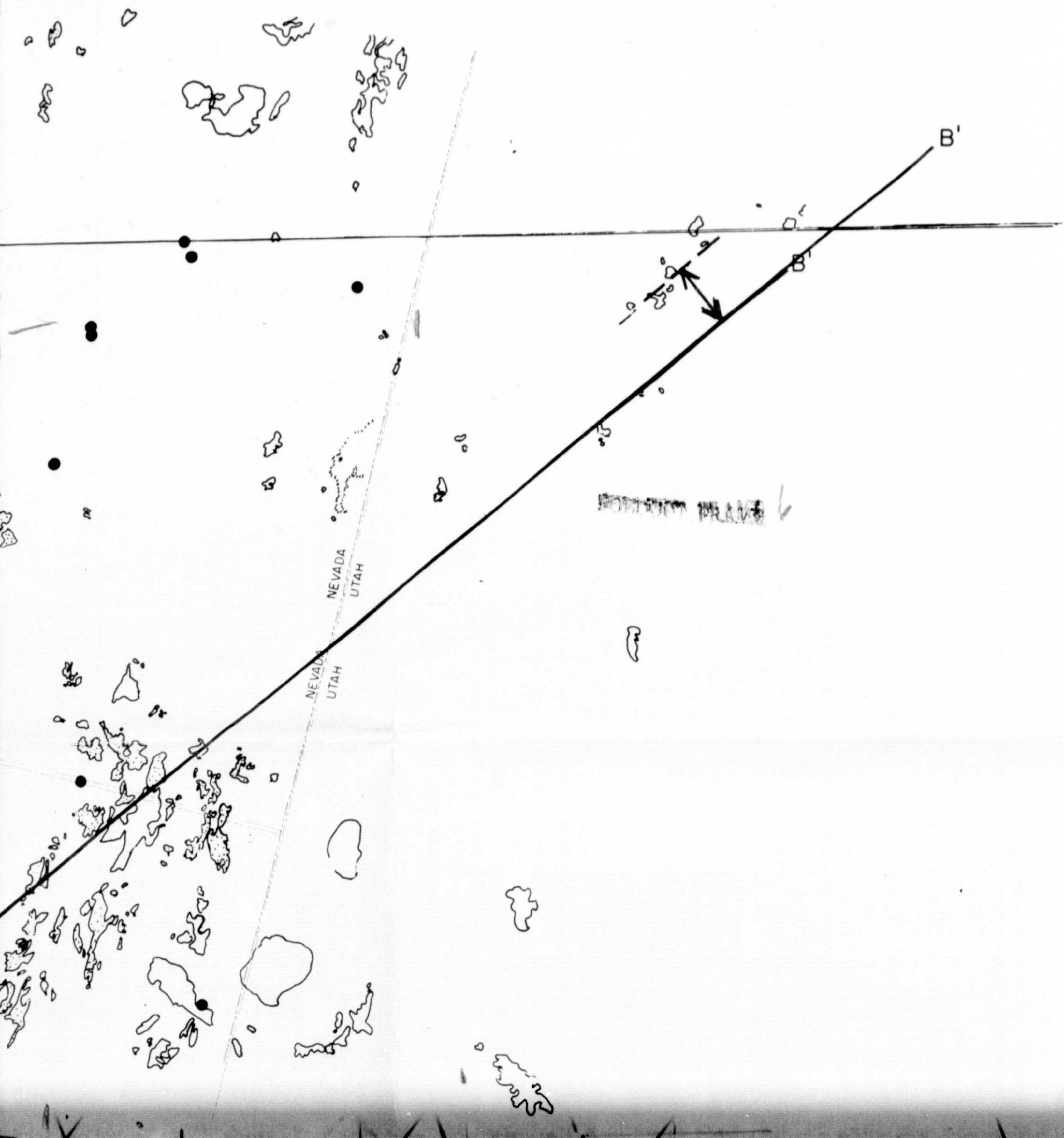
PLATE 7

XTRUSIVE OUTCROPS

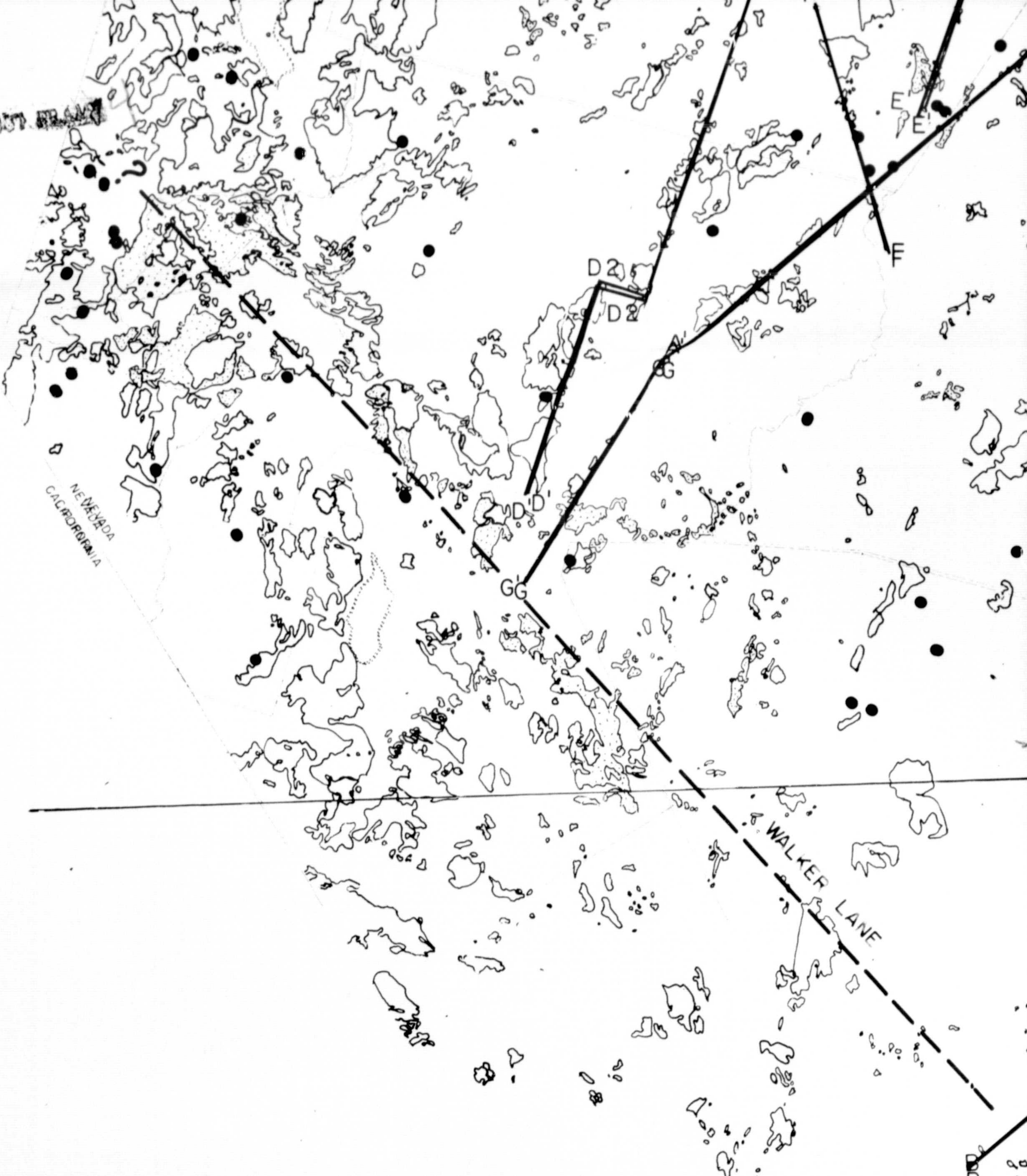

D1
D2
F'
F
E
E'
G
G'
D
D'
NEVADA
CALIFORNIA

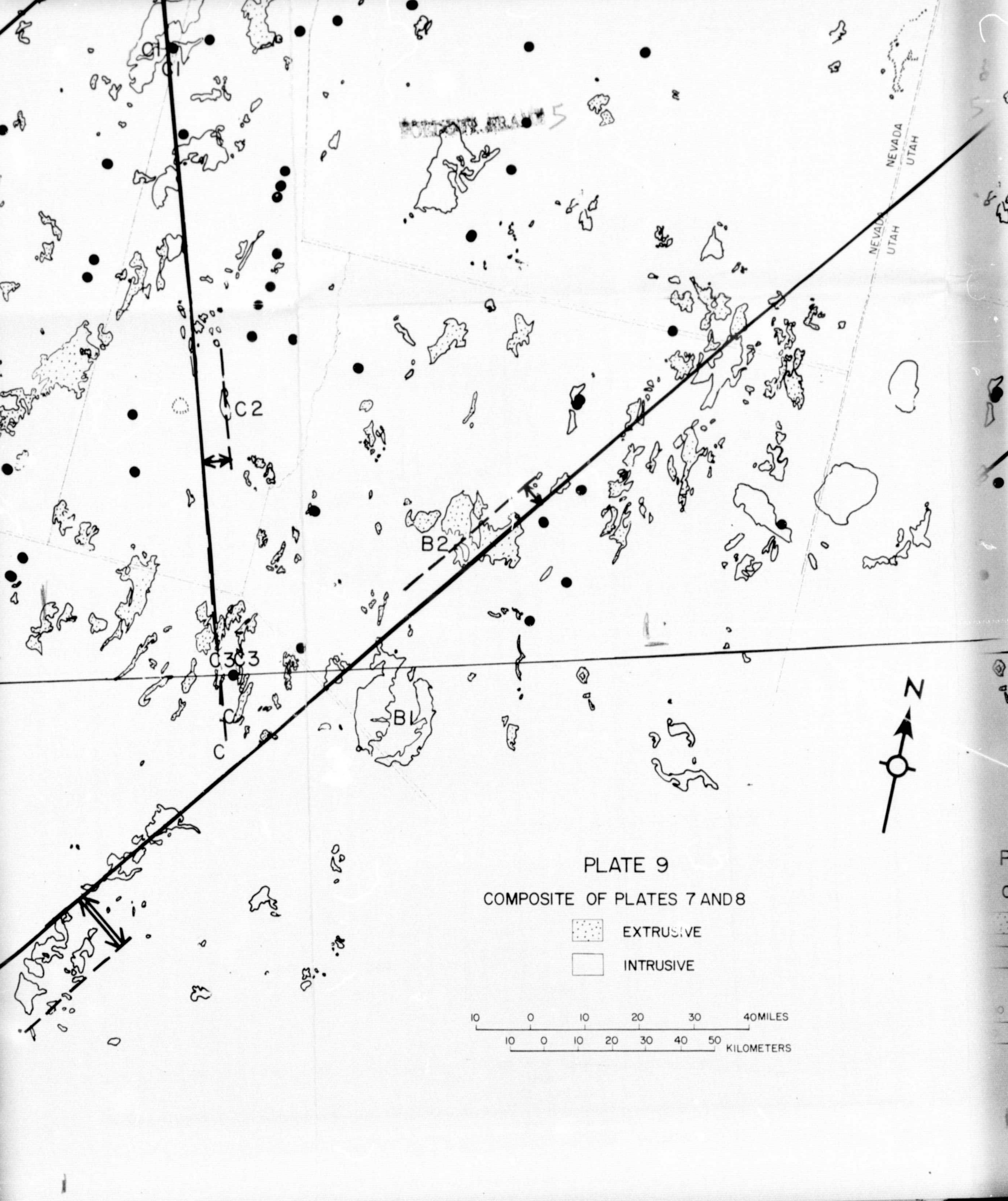

D
E
AA
C'
C'
D1
E1
C1
C1
C2
B2
NEVADA
UTAH
NEVADA
UTAH

FOLDOUT FRAME 3



FOLDOUT FRAME 4


NEVADA
CALIFORNIA
D2
D2
D
D'
G
G'
E
E'
F
WALKER LANE
B
B


C1
C1
NEVADA
UTAH
NEVADA
UTAH
C2
B2
C3C3
B1
C
C
N
PLATE 9
COMPOSITE OF PLATES 7 AND 8
EXTRUSIVE
INTRUSIVE
10 0 10 20 30 40 MILES
10 0 10 20 30 40 50 KILOMETERS

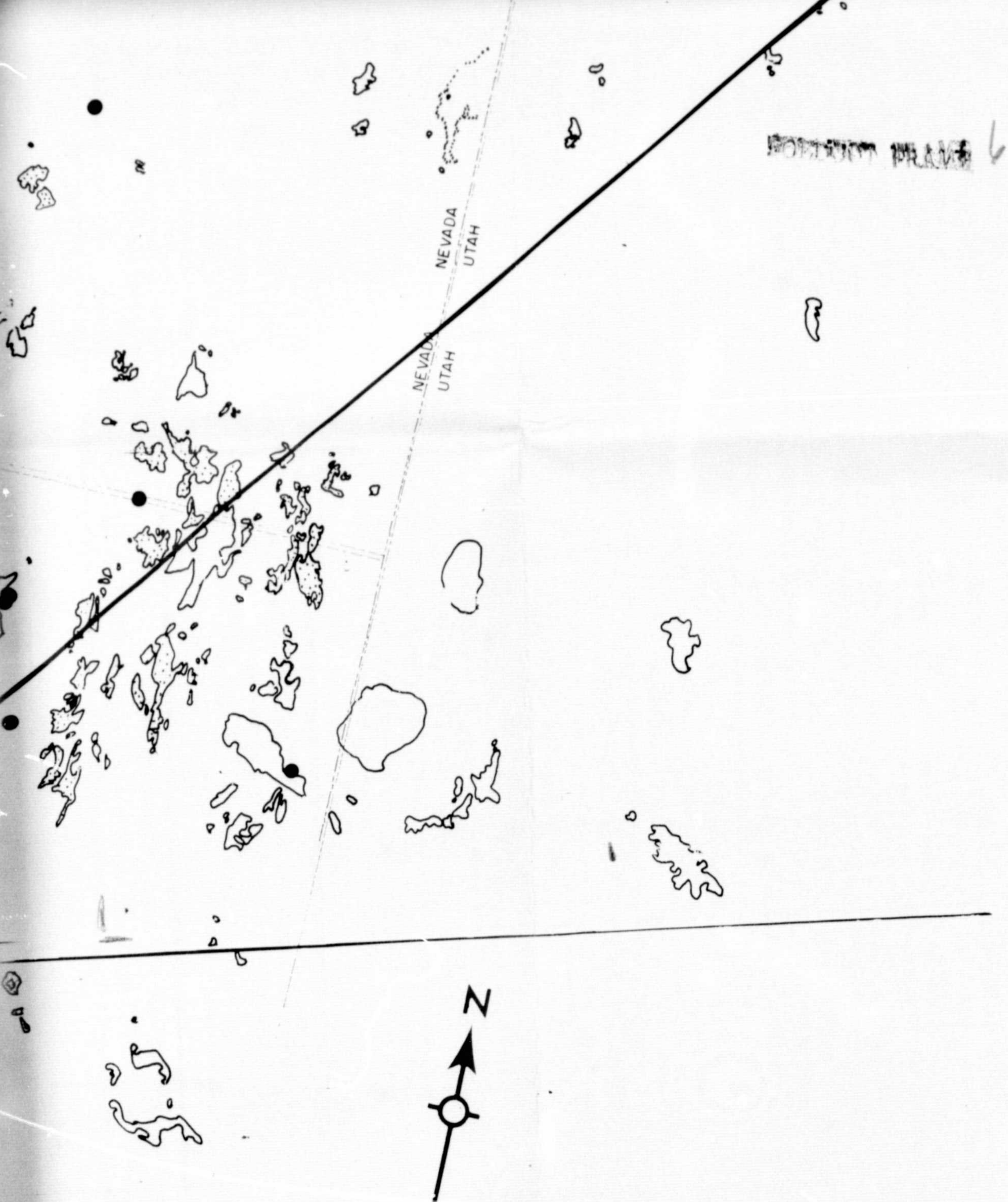


PLATE 9

OF PLATES 7 AND 8

EXTRUSIVE

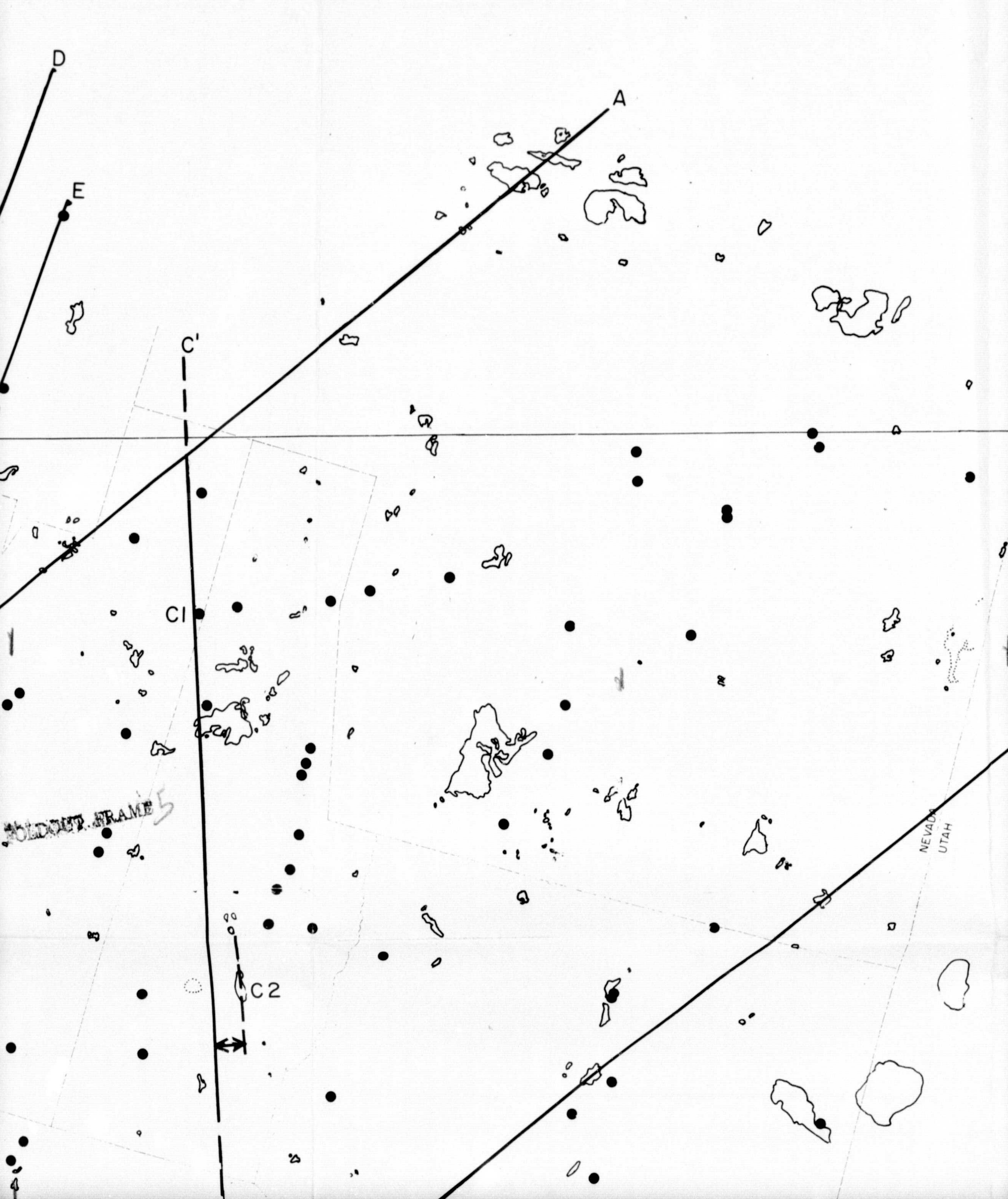
INTRUSIVE

20 30 40 MILES

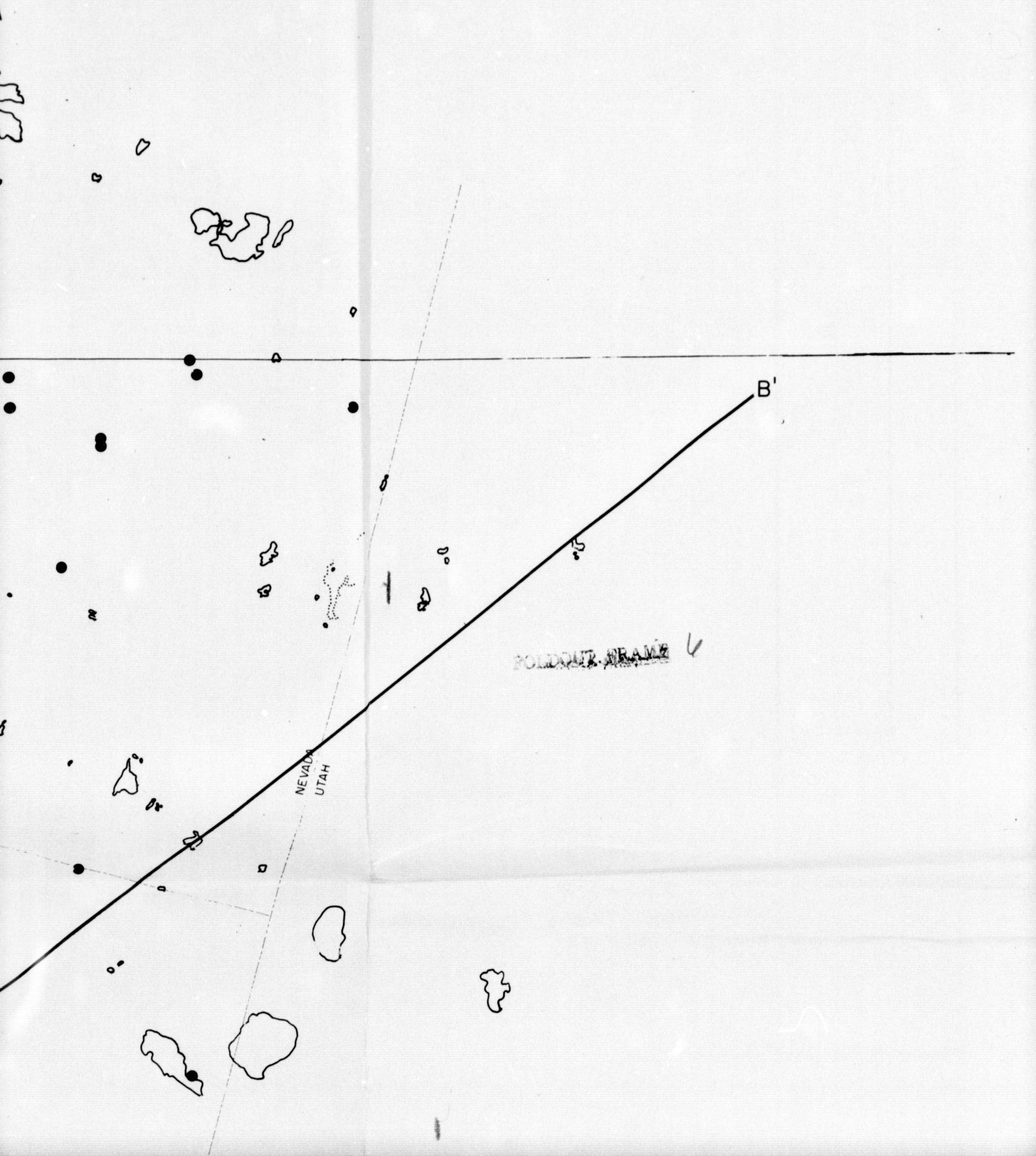
20 30 40 50 KILOMETERS

FOLDOUT FRAME

FOLDOUT FRAME 2



FOLDOUT FRAME 3



FOLDOUT FRAME 4


E'
F
D2
A'
G
D'
NEVADA
CALIFORNIA
G
B

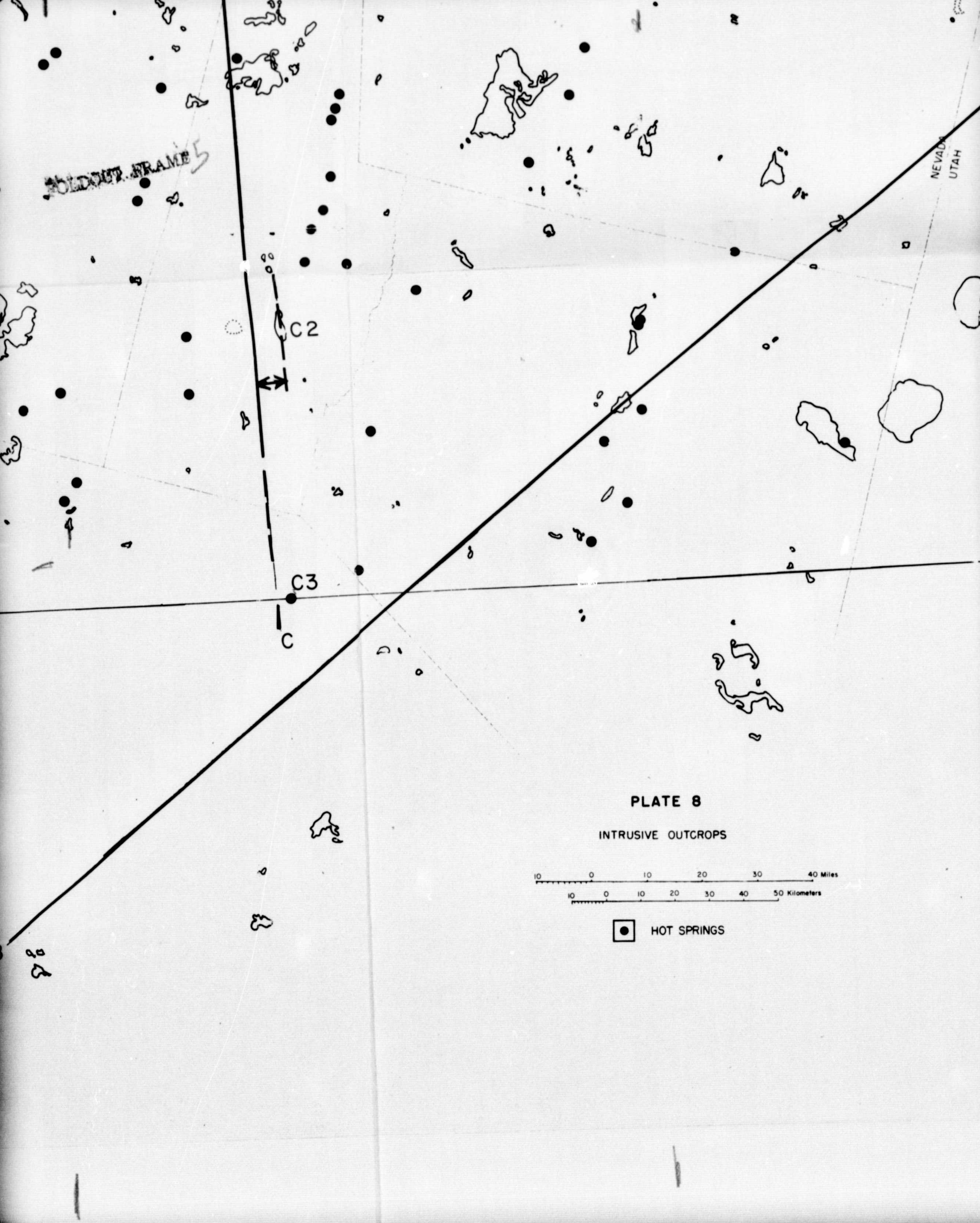
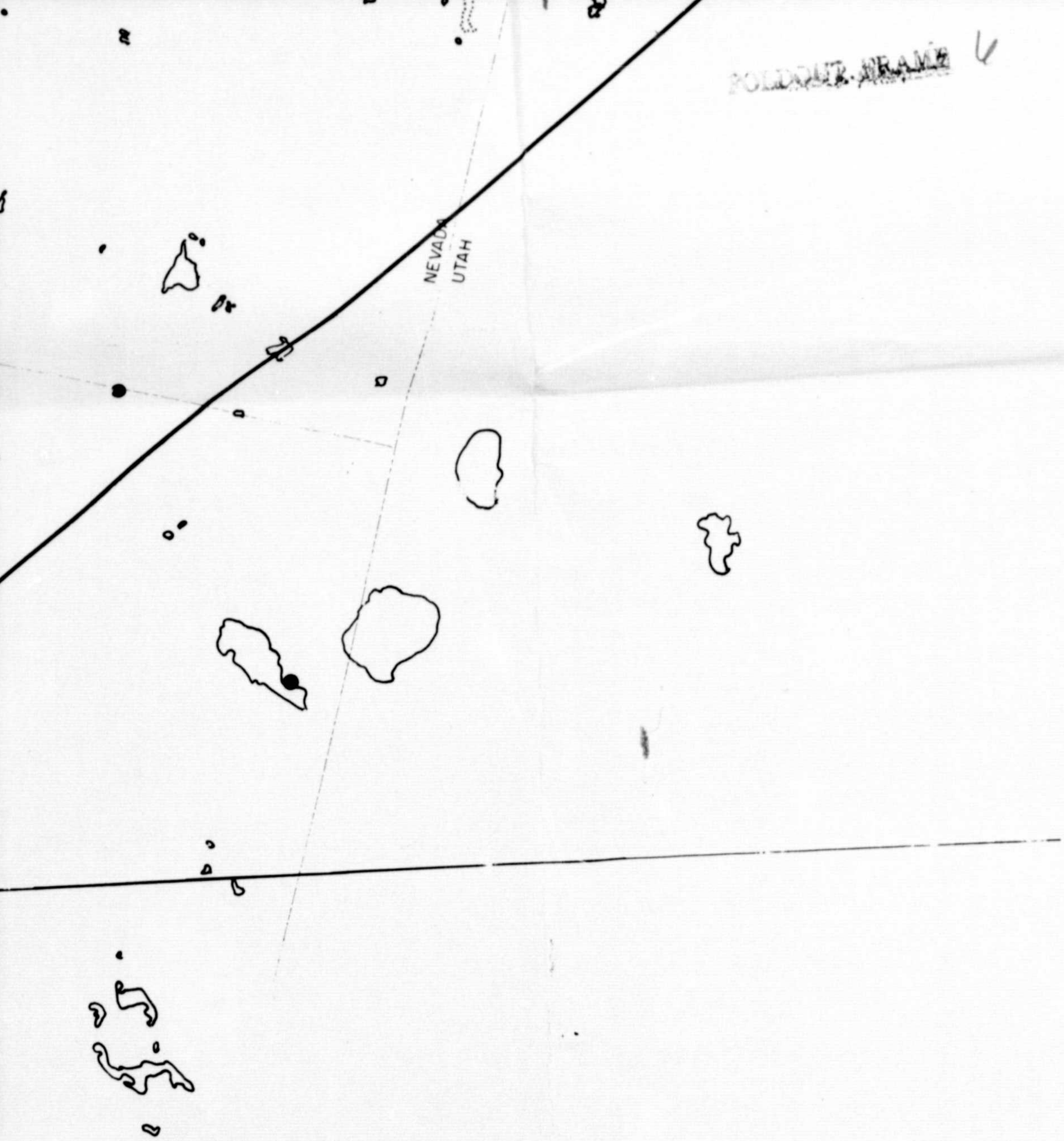


PLATE 8

INTRUSIVE OUTCROPS



ATE 8

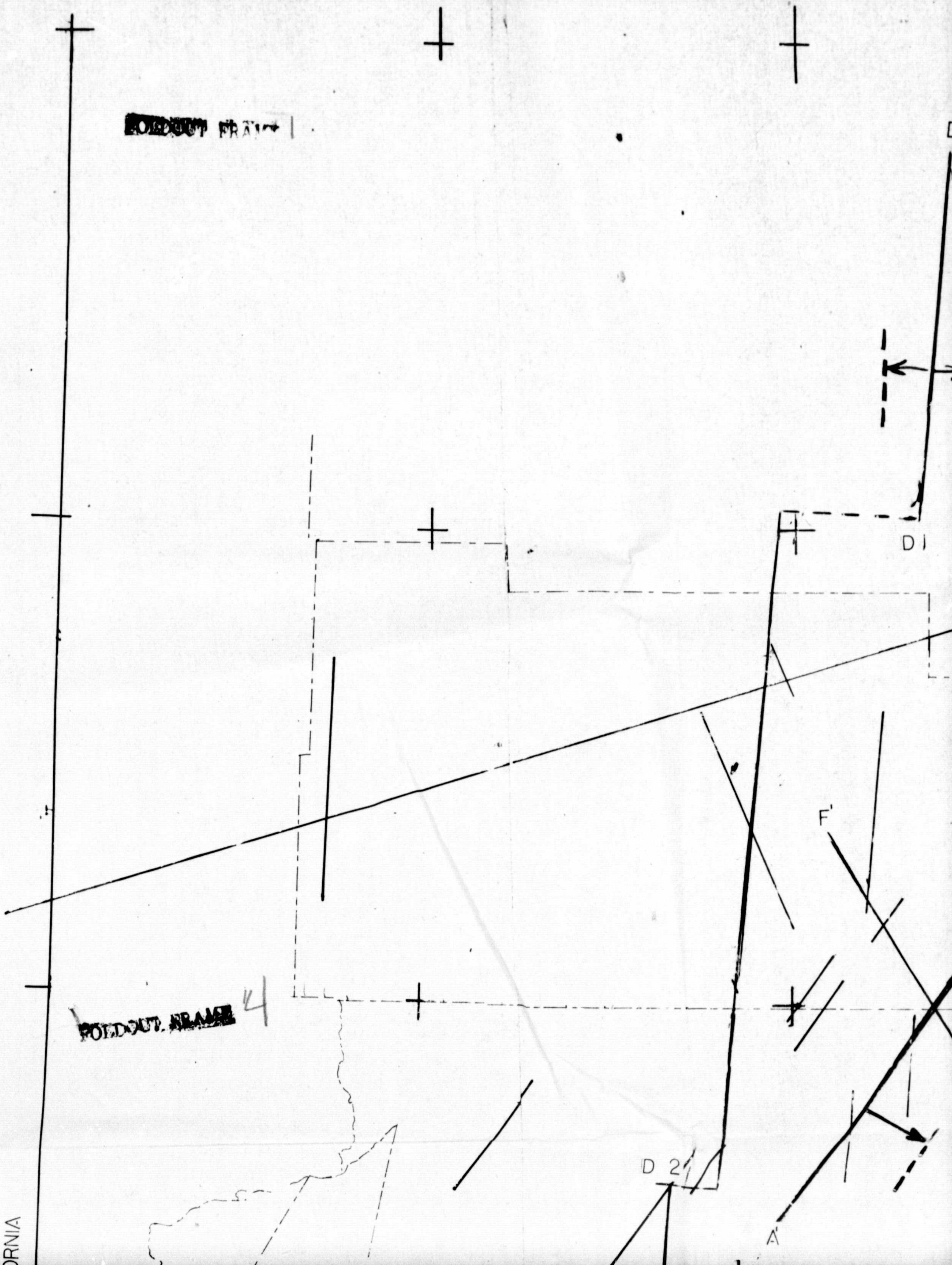
E OUTCROPS

20 30 40 Miles

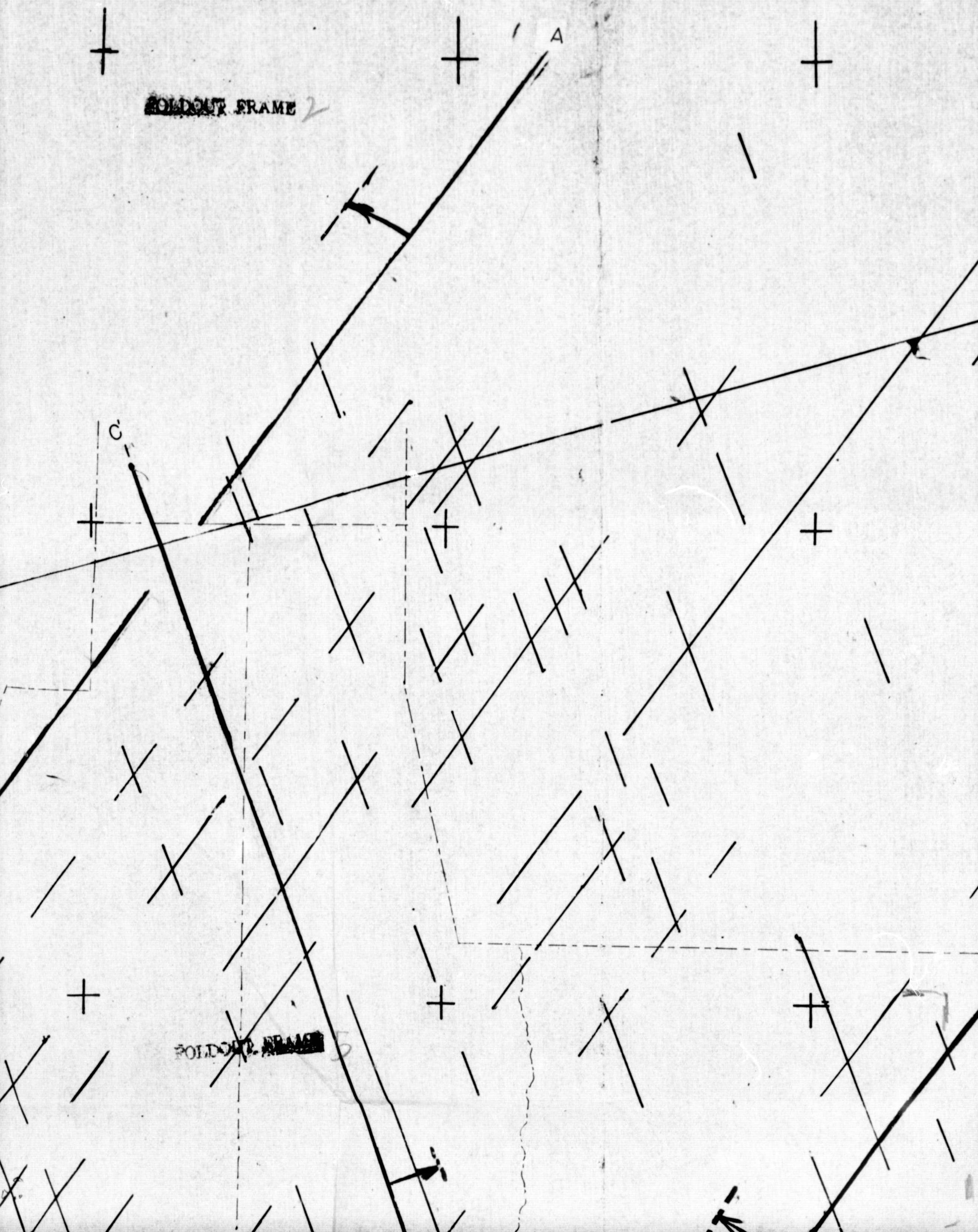
20 30 40 50 Kilometers

HOT SPRINGS

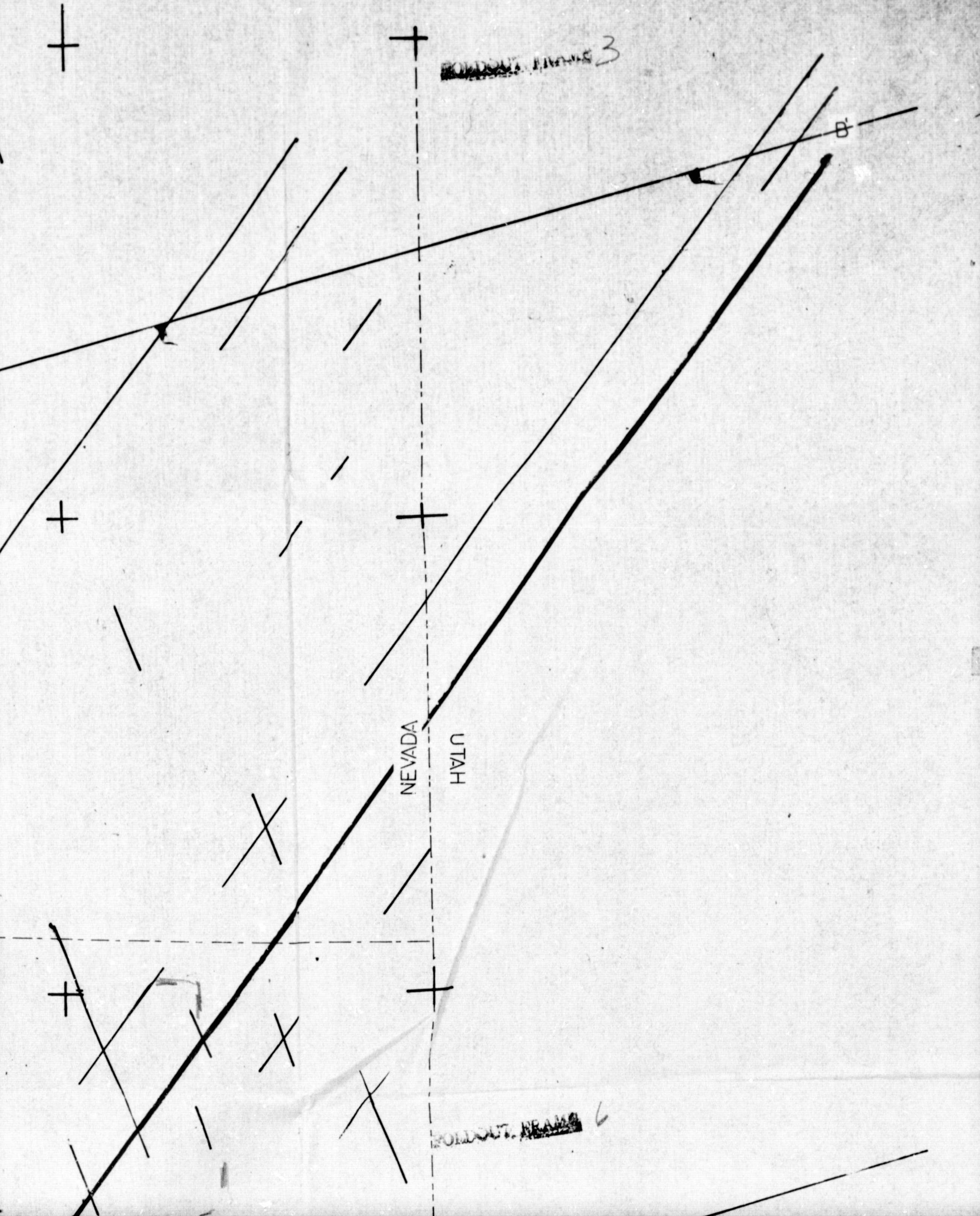
FOLDOUT FRAME 1



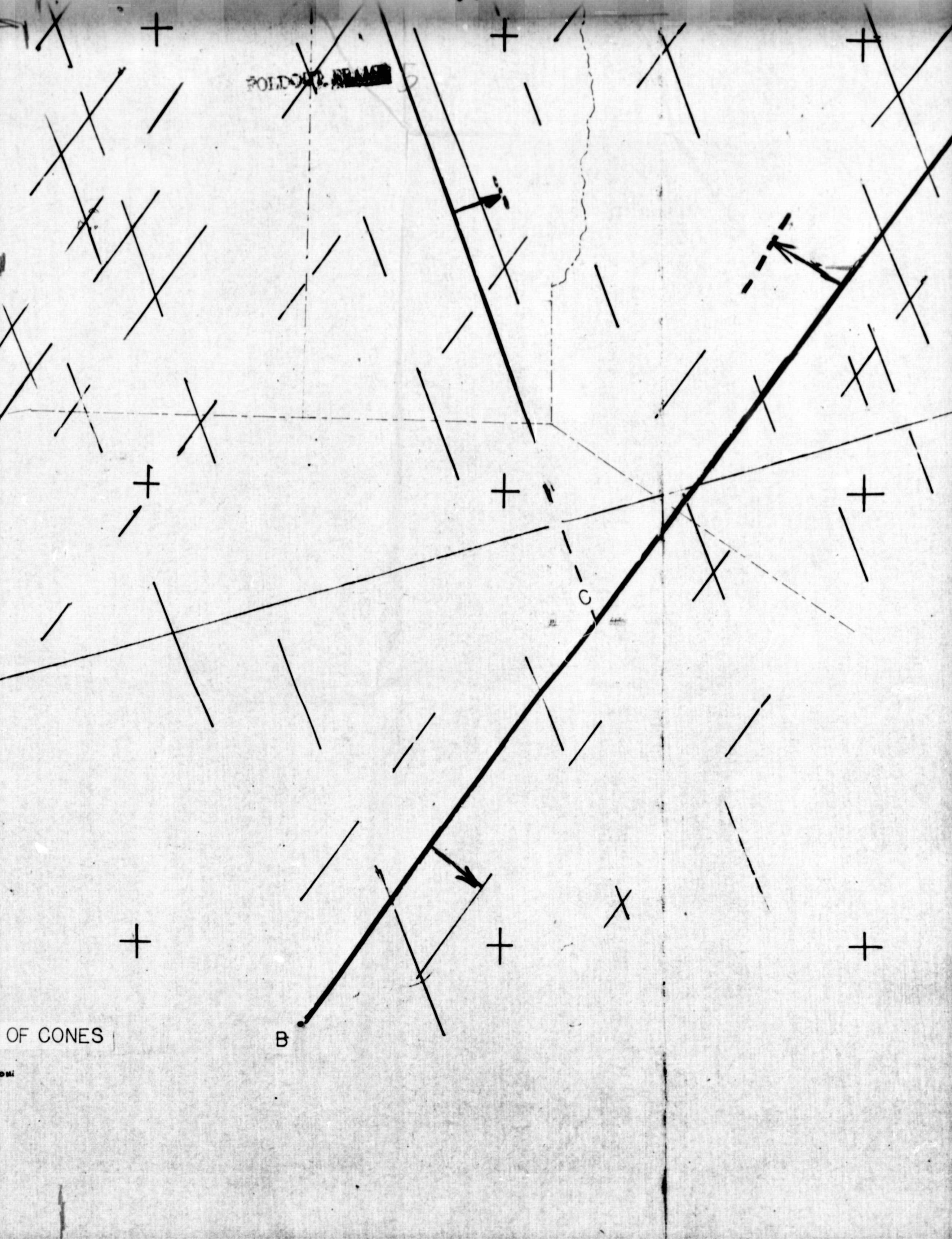
FOLDOUT FRAME 4

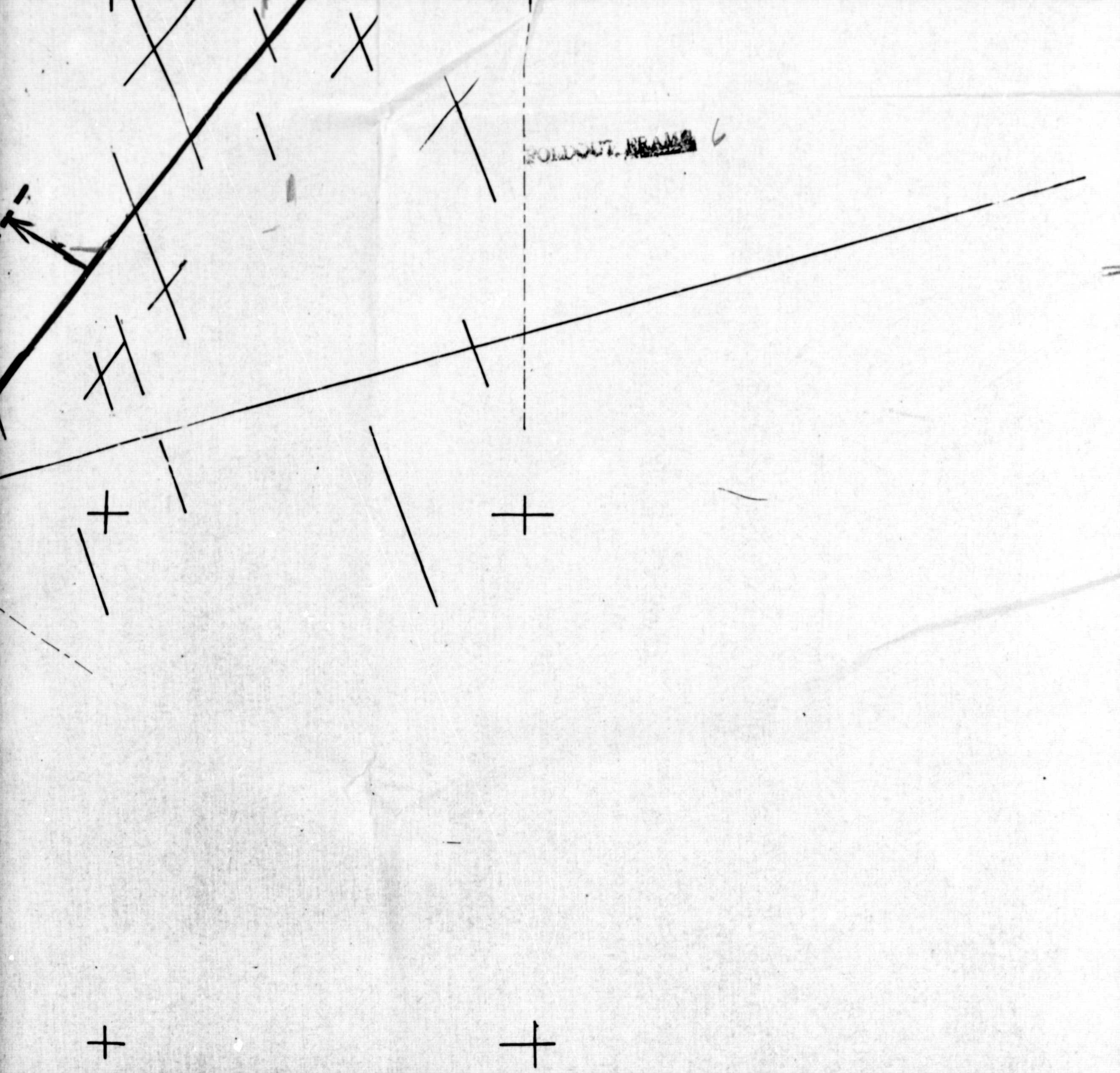

A
C
FOLDOUT FRAME 2
FOLDOUT FRAME 5

FOLDOUT FRAME 3



FOLDOUT FRAME 6


FOLDOUT FRAME
C
B
OF CONES



FOLDOUT FRAME 6

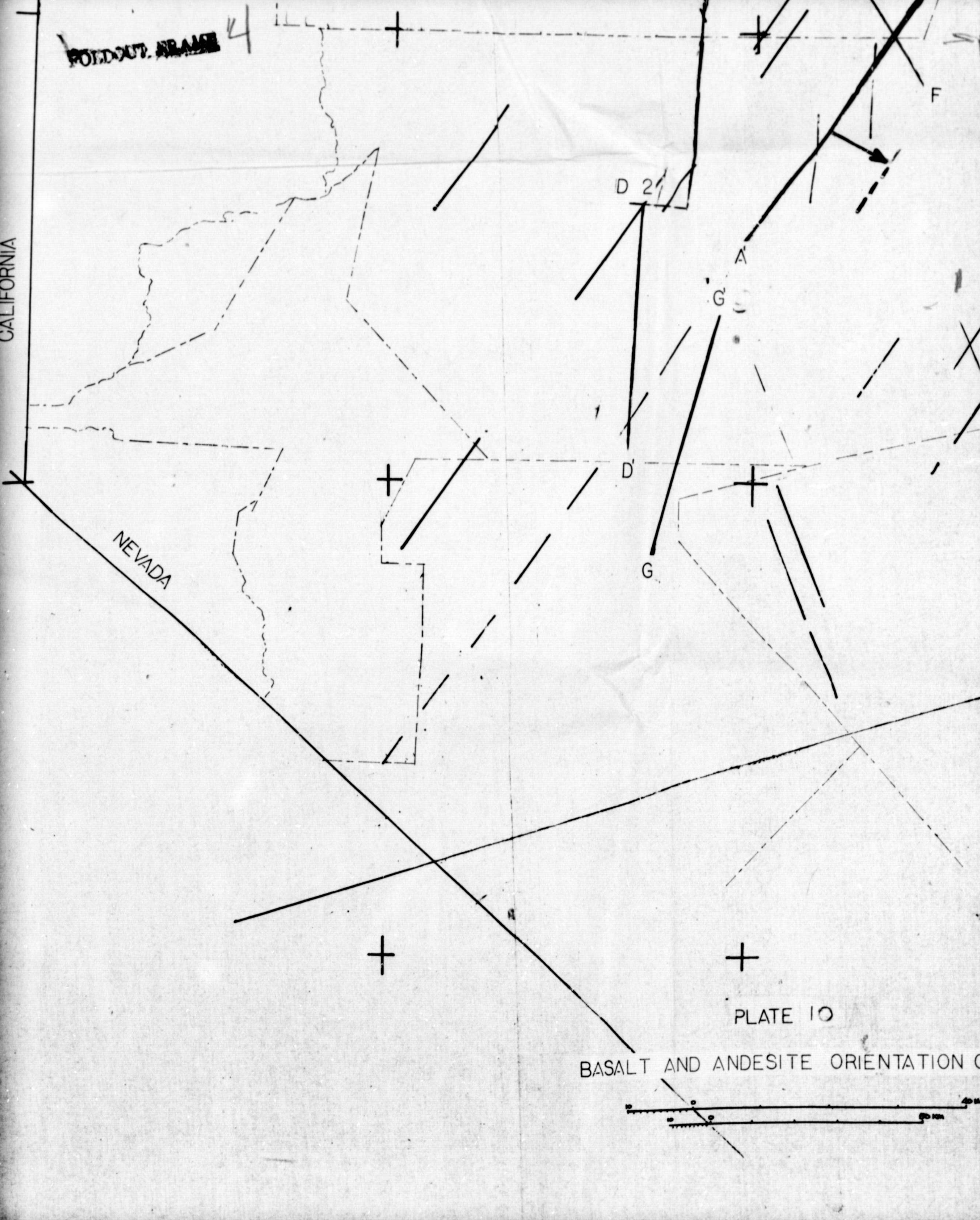


PLATE 10

BASALT AND ANDESITE ORIENTATION C